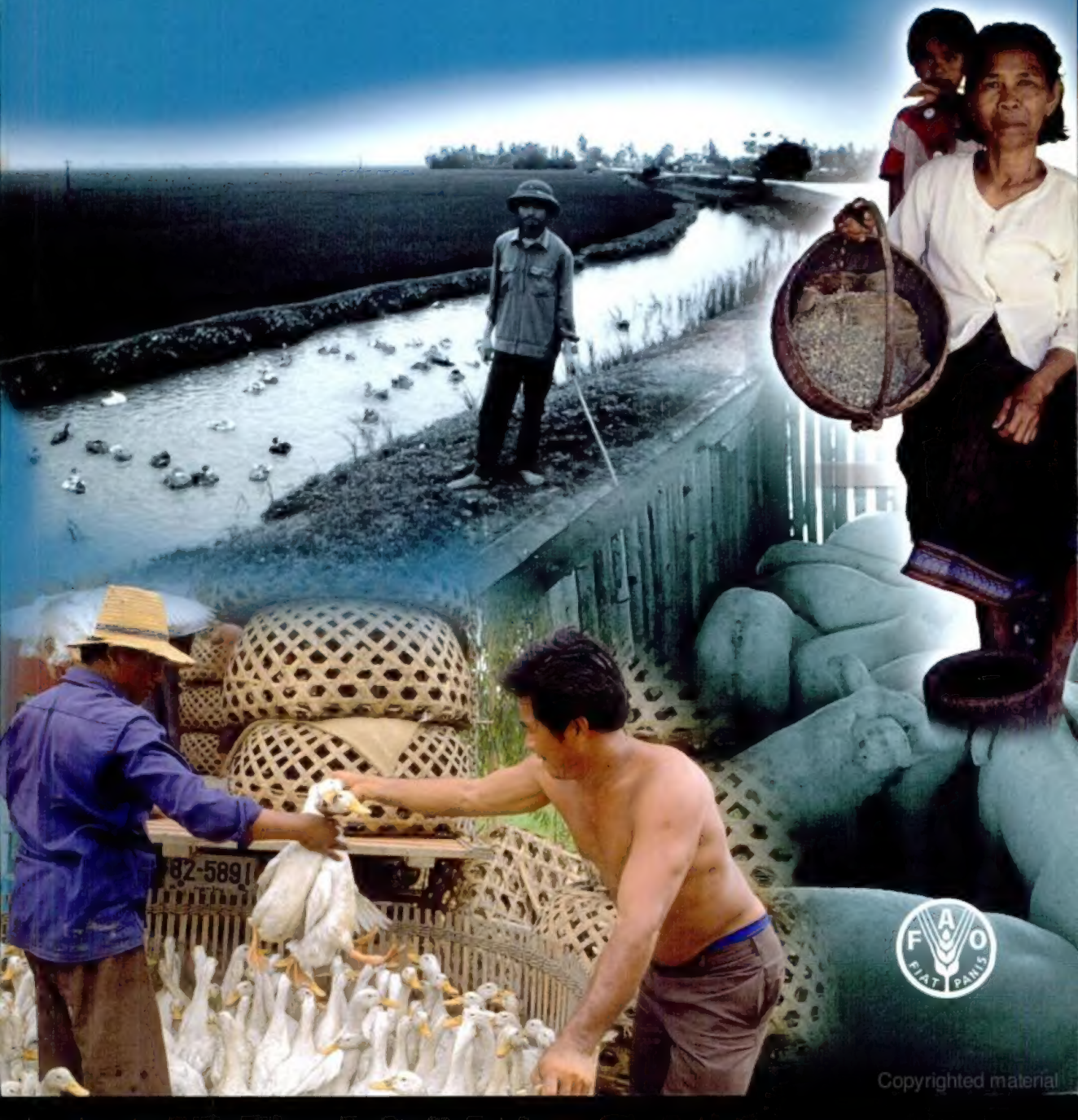
Integrated livestock-fish farming systems



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Integrated livestock-fish farming systems

BY D.C. LITTLE AND P. EDWARDS

INLAND WATER RESOURCES AND AQUACULTURE SERVICE
ANIMAL PRODUCTION SERVICE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Preface

Small farmers in developing countries are poorer than the rest of the population, often not getting enough food to lead normal, healthy and active lives. Dealing with poverty and hunger in much of the world therefore means confronting the problems that small farmers and their families face in their daily struggle for survival. One option for economically and ecologically sustainable development of farming systems is the integration of agriculture and aquaculture.

The various types of aquaculture form a critical component within agricultural and farming systems development that can contribute to the alleviation of food insecurity, malnutrition and poverty through the provision of food of high nutritional value, income and employment generation, decreased risk of production, improved access to water, sustainable resource management and increased farm sustainability.

Livestock production and processing generate by-products that may be important inputs for aquaculture. The main linkages between livestock and fish production involve the direct use of livestock wastes, as well as the recycling of manure-based nutrients which function as fertilizers to stimulate natural food webs.

On a global basis, most cultured freshwater fish are produced in Asia in semi-intensive systems that depend on livestock wastes purposely used in ponds, or draining into them. Much of the vast increase in China's recent inland aquaculture production is linked to organic fertilization, provided by the equally dramatic growth of poultry and pig production. The use of livestock wastes is still needed, even when high-quality supplementary feeds are available and they are still widely used in more intensive aquaculture systems.

The objective of the publication is to provide an analysis of the evolution and current status of integrated livestock-fish systems in Asia, particularly East and Southeast Asia, as well as to provide a sound technical basis for considering their relevance for the planning of livestock-fish systems in Africa and Latin America.

It is hoped that the conclusions and recommendations presented here will be interesting and thought-provoking for a wide audience generally interested in the subject of integrated agriculture-aquaculture, and particularly policy makers, planners, NGOs and senior research and extension staff. It is hoped that the book will stimulate these people at all levels to ensure that agricultural development provides for reasonable rural livelihoods, a clean environment, and adequate food products.

Jiansan Jia - Chief, Inland Water Resources and Aquaculture Service

Irene Hoffmann - Chief, Animal Production Service

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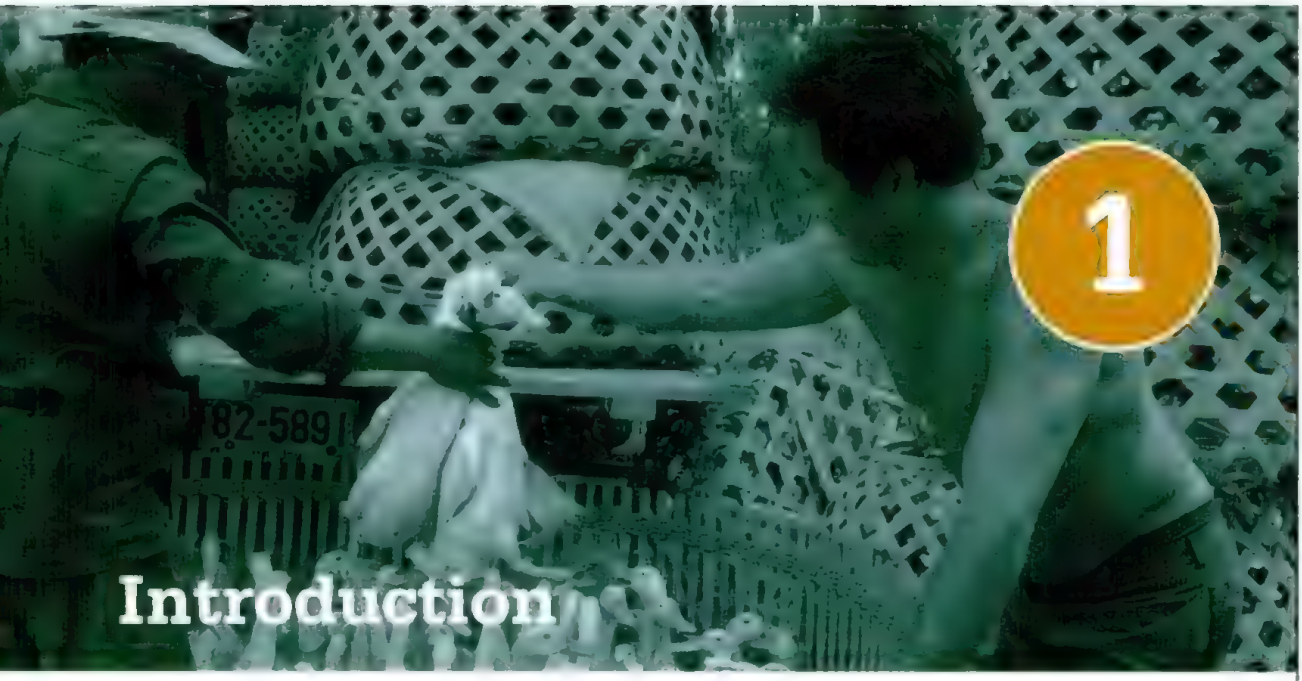

1 Introduction

Aquaculture is the fastest growing food production sector in the World with annual growth in excess of 10 percent over the last two decades. Much of this development has occurred in Asia, which also has the greatest variety of cultured species and systems. Asia is also perceived as the 'home' of aquaculture, as aquaculture has a long history in several areas of the region and knowledge of traditional systems is most widespread. Furthermore, the integration of livestock and fish production is best established in Asia.

In this initial section we introduce the rationale for the study and provide definitions of integrated livestock–fish farming. We then examine the current status and future importance of livestock and fish production being integrated rather than being developed further as specialized, separate activities. Their sustainability and importance in a broader context are then considered

1.1 Rationale of the study

Livestock–fish production systems develop to satisfy needs if they fit into the resource base or environment, and if they are socially and economically viable. Macro-level factors may also have a significant influence and there are environmental implications, both on- and off-farm, for the development of sustainable systems (Figure 1)

The current status of livestock–fish systems reflects their evolution in response to changing circumstances: the past history of current systems is not generally appreciated; nor is their future potential apparent.

The rationale for this study is to interpret Asian, especially East and Southeast Asian experience in integrated systems through analysis of their evolution and current status and to consider their relevance for livestock–fish planning in Africa and Latin America

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The development of sustainable aquaculture systems involves consideration of production technology, social and economic aspects, and environmental aspects

Source: AIT (1994)

1.2 Definitions of integrated farming

Integrated farming is commonly and narrowly equated with the direct use of fresh livestock manure in fish culture (Little and Edwards, 1999). However, there are broader definitions that better illustrate potential linkages. Indeed, the term "integrated farming" has been used for integrated resource management which may not include either livestock or fish components. Our focus is the integration of livestock and fish, often within a larger farming or livelihood system. Although housing of livestock over or adjacent to fish ponds facilitates loading of wastes, in practice livestock and fish may be produced at separate locations and by different people yet be integrated. Chen *et al.* (1994) distinguished between the use of manures produced next to the fishpond and elsewhere on the same farm. A wider definition includes manures obtained from off-farm and transported in bags, e.g. poultry manure, or as a slurry in tanks, such as for pig and large ruminant manure.

Integrated farming involving aquaculture defined broadly is the concurrent or sequential linkage between two or more activities, of which at least one is aquaculture. These may occur directly on-site, or indirectly through off-site needs and opportunities, or both (Edwards, 1997). Benefits of integration are synergistic rather than additive; and the fish and livestock components may benefit to varying degrees (Figure 2). The term "waste" has not been omitted because of common usage but philosophically and practically it is better to consider wastes as "resources out of place" (Taiganides, 1978).

1.3 Potential linkages between livestock and fish production

The main potential linkages between livestock and fish production concern use of **nutrients**, particularly reuse of livestock manures for fish

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production. The term nutrients mainly refers to elements such as nitrogen (N) and phosphorous (P) which function as fertilizers to stimulate natural food webs rather than conventional livestock nutrition usage such as feed ingredients, although solid slaughterhouse wastes fed to carnivorous fish fall into the latter category. There are also implications for use of other resources such as capital, labour, space and water (Figure 3). A variety of factors affect potential linkages between livestock and fish production (Box 1.A)

Both production and processing of livestock generate by-products that can be used for aquaculture. Direct use of livestock production wastes is the most widespread and conventionally recognized type of integrated farming. Production wastes include manure, urine and spilled feed; and they may be used as fresh inputs or be processed in some way before use.

Use of wastes in static water fishponds imposes limitations in terms of both species and intensity of culture. Stimulation of natural food webs in the pond by organic wastes can support relatively low densities of herbivorous and omnivorous fish but not a large biomass of carnivorous fish. These biological processes are also temperature dependent. The optimal temperature range is between 25-32°C although

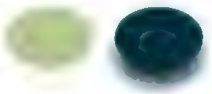
BOX 1.A

Checklist of key issues affecting linkages between livestock and fish production

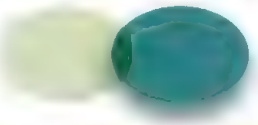
- **Is there demand for fish species capable of feeding on natural foods generated by fertilization using livestock wastes?**
- **Are the livestock monogastrics or ruminants?**
- **Can the wastes be cost effectively collected?**
- **Will legislation require processing of wastes before use for fish culture?**
- **Do livestock wastes have a high opportunity cost?**
- **Will low ambient temperatures (<18°C) restrict waste-fed aquaculture?**
- **Is fish culture already established based on conventional feeds and systems?**

FIGURE 2

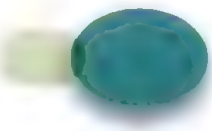
Potential outcomes of livestock-fish integration



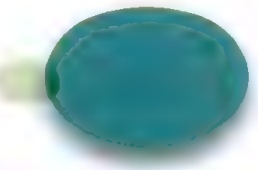
Separate, stand alone operations



Integration results in similar levels of benefit to both components, which increases overall benefit



Integration increases level of benefit of one component and has a neutral effect on the other



Small declines for one component are compensated for the large increase in the other

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waste-fed aquaculture in sub-tropical and temperate zones where temperatures rise seasonally has also been successful. Processing wastes through organisms such as earthworms and insect larvae that feed on them and concentrate nutrients to produce 'live feeds' is an alternative approach to raising fish needing high levels of dietary animal protein. Livestock processing can also provide a wide variety of wastes that vary from dilute washing water to high value meat and bloodmeal that can be used as high value fish feeds or feed ingredients. If enough of these types of feeds are available, high density and intensive production of carnivorous fish species can be supported. Aquaculture may also provide inputs and other benefits to livestock production. A variety of aquatic plants e.g duckweeds and the aquatic fern *Azolla* have proven potential as livestock feeds; and invertebrates such as snails and crustaceans can be used for poultry feeds

Our study focuses on the integration of fish and livestock. The use of cultured fish or fish products as livestock feeds, although currently uncommon, holds promise and is reviewed. Other, more minor beneficial linkages between fish and livestock production include use of fish culture water for drinking/bathing livestock and cooling livestock housing. Nutrients contained in culture water and sediments may be used to produce arable crops for livestock. The viability of these options depends on a variety of factors, including the types of livestock and fish that can be raised profitably and the production systems used

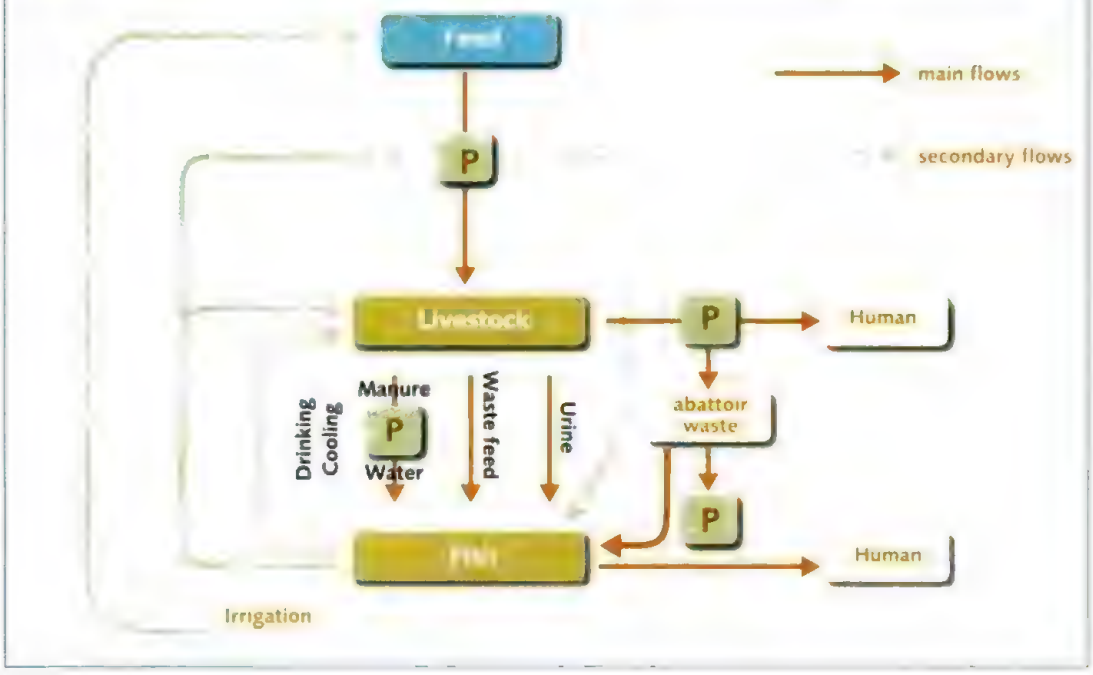
1.4

Relevance of integrated farming

The integration of fish and livestock production is probably closer today, and more important than ever before (FAO, 2000). On a global basis most cultured freshwater fish are produced in Asia in semi-intensive systems that depend on fertilizer

FIGURE 3

Main and secondary linkages in livestock–fish integration (P = processing)



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nutrients. Moreover, with increasing need for multipurpose use of water resources, community water bodies used for watering livestock are increasingly stocked with fish seed and their management intensified. Several studies of small-holder aquaculture in Bangladesh, India, Thailand and Viet Nam indicate that livestock wastes are the most commonly used input. Fish yields may not be optimized for a variety of reasons but livestock wastes purposely used in ponds, or draining into them, support the production of most cultured fish in Asia.

An analysis of China, the ancestral home of aquaculture, indicates that whilst intensive practices based on formulated pelleted feed are developing rapidly, much of the vast increase in China's recent inland aquaculture production is linked to organic fertilization, provided by the equally dramatic growth of poultry and pig production. Trends in those parts of Asia which are undergoing rapid industrialization and urbanization suggest that livestock–fish systems can retain a relative advantage over intensive aquaculture for production of low-cost carps and tilapias. A strong link to the use of livestock wastes remains even when high-quality supplementary feeds are available and widely used.

A major issue is the potential competition for, and relative efficiency of the use of, limited amounts of feeds between livestock and farmed fish. This has both local and global implications. Supplementary feeds, such as ricebran and oil cakes, which are traditionally fed to livestock, are often in demand for feeding fish. Continued growth in demand for livestock and fish has raised alarm bells over the sustainability of feed supplies and the impacts of such growth on the environment.

1.6 Sustainability issues at micro- and macro-levels

Sustainability may be considered at global, national, regional, community and household level and from a variety of perspectives. Sustainability as defined by an ecologist, may be very different to that by an economist, but most can support the essence of that in the Brundtland Report (WCED, 1987) which incorporates social and economic as well as environmental concerns. Important questions relate to the role of integration of aquaculture with livestock to improve sustainability of food production in socially and economically advantageous ways while safeguarding or improving the environment. For this to occur, the roles of culture and institutions both have to be considered also since they are major forces for change or conservatism. A major issue of this book is how integration, rather than specialization and separation, of livestock and fish production can enhance sustainability at all levels and perspectives.

BOX 1.B

A widely used definition of sustainability

"Sustainable development is that which meets the needs of the present without compromising the ability of future generations to meet their own needs"

Source: WCED (1987)

The interpretation and measurement of sustainability have become focal points of rural development. In a smallholder farmer's world, key parameters of sustainability have been identified as high levels of species diversity, nutrient cycling, capacity (total production) and economic efficiency (Lightfoot *et al.*, 1993; Bimbao *et al.*, 1995; Dalsgaard *et al.*, 1995). At the micro-level, watershed, community, farm, plot and pond may be used as a basis for assessing sustainability, but the role of people is central to development.

Most poor rural people do not rely entirely on their own land to sustain them. Typical livelihoods are complex and depend on a variety of resources, many of which are off-farm (Ellis, 1992). At the heart of the issue of 'sustainability' are peoples' livelihoods (Box 1.C). Holistic

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thinking is required to analyse and describe livelihoods with a focus on peoples' relative strengths rather than 'needs'. Building up assets is a core component of empowerment (Figure 4). How the inclusion of intensified management of aquatic resources can support, or detract, from this process is indicated in Table 1.1.

People base their livelihoods on a range of assets in addition to financial capital that include natural, human, physical and social capital. A pentagon can represent these five types of asset or capital although in practice there is overlap between them (Figure 4). Understanding trends in peoples' assets over time can indicate if positive or negative developments are occurring, and if livelihoods are deteriorating or improving. The approach can be applied on a community, group or household level to inform and guide the development process. Knowing about the assets of different wealth and social groups in the same community can allow better targeting of poorer people and monitoring of changes that occur. The impacts of shocks of various types, and how assets are used to reduce vulnerability, are important aspects of assessing livelihoods.

Forging links between ecosystem theory and farming system analysis (Dalsgaard *et al.*, 1995) can be useful, provided that the results are placed within a broader framework of sustainability issues. A range of different system attributes has been identified that provides measures of how livestock and fish can improve sustainability of farming systems (Table 1.2). As sub-systems within the wider farming system (Edwards *et al.*, 1988), fish culture and livestock can improve nutrient recycling and concentration. This feature is important in both nutrient-rich, peri-urban systems and nutrient-poor rural situations (Little and Edwards, 1999). Diversity, stability and capacity can all be enhanced through inclusion of livestock

BOX 1.C

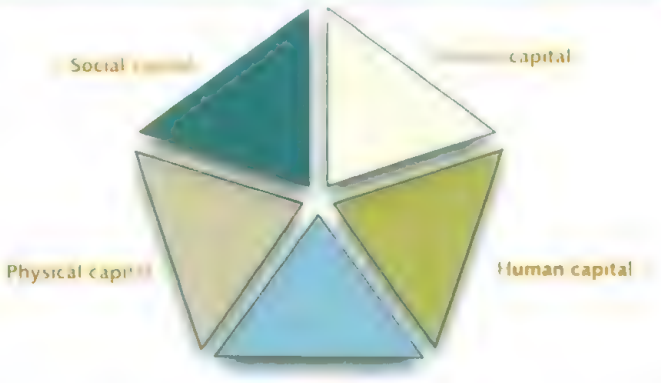
Livelihoods defined

"A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base".

Source: Carney (1998)

FIGURE 4

Asset pentagon to analyse sustainable rural livelihoods



Source: Carney (1998)

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TABLE **1.1**

How the integration of fish culture into small-holder crop/livestock systems affects asset accumulation and livelihoods

Natural	• Reduced pressure on remaining natural aquatic resources can relieve pressures on biodiversity and integrity of remaining natural habitats	• Increased pressure on natural resource stock for water, nutrients and fish seed
Social	• Increased fish and other aquatic products available for enhancing social relationships	• Increased discordance on use of resources within household, increased opportunities for theft, increased conflicts over water (quantity and quality) available for other purposes
Human	• Skills and knowledge developed that can be used to further diversify livelihood strategies • Improved nutrition enhances physical and mental health	• Competition with more vital activities for time and attention • Extra labour burden and change in use of nutrient resources could reduce physical and mental health
Physical	• Improved potential for diversification of farming systems and livelihoods generally through transformation of land and water holding to reduce risk to both flood and drought • Physical assets may be multipurpose e.g. for communication and machinery	• Reduced area available for staple crops
Financial	• Improved overall income and regularity of income, credit worthiness, and savings • More diversified production reduces financial risk	• High investment cost for pond construction may cause indebtedness that poor subsequent management cannot repay

Framework for role of capital assets in sustainable livelihoods adapted from Scoones (1998) and Carney (1998)

and fish on farms, as can both economic efficiency and the scope for future change or 'evolvability'

The greater ecological similarity of low external input than intensive systems to natural ecosystems reduces adverse environmental impacts (Kautsky *et al.*, 1997). But very low input systems, especially in nutrient-poor environments, may not adequately support livelihoods, driving poor people to ever more extractive and unsustainable practices off-farm. Small external nutrient injections may enhance performance or help to regenerate degraded agro-ecosystems (Kessler and Moolhuijzen, 1994). The productivity and stability of farming systems in Machakos, Kenya, improved considerably as incomes from off-farm employment were reinvested in agro-forestry, livestock and horticulture. Intensification of livestock and soil management have also reduced land degradation in heavily populated parts of Uganda (Lindblade *et al.*, 1998). Integration of livestock and fish at a community or watershed level may have more potential than household-level in some situations

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TABLE **1.2**

How livestock and fish improve the sustainability of farming systems

System attribute	Livestock
Nutrient recycling	Feeding crop byproducts such as ricebran and terrestrial and aquatic plants to livestock increases recycling of nutrients within the farm. Pigs are used particularly for this purpose in parts of China and SE Asia
Nutrient concentration	Feeding off- and on-farm feeds can allow concentration of nutrients, and act as a pathway for nutrients to be cost -effectively gathered or harvested from common property. Ruminants are important for this aspect of enhanced sustainability
Diversity	Most small-holder farms manage a range of livestock that utilize the variety of feed resources available. Important advantages include pest control, recycling, manageability, economic reasons (risk aversion and cash flow)
Stability (resistance to change)	Livestock are a stabilizing influence, reducing perturbation on households during time of physical or social stress. Their variety of uses (draught, fertilizer, social value, fuel, cash, food) allows small holders to better maintain productivity when faced with change
Capacity	Livestock waste improves soil quality and fertility, grazing can improve species richness and reduce soil erosion
Economic efficiency	Livestock products are often the major source of cash in small-holder systems. Having a variety of livestock types improves versatility with respect to investment, cash flow and risk aversion
Evolvability	Dominance of commercial livestock systems threatens the scope for small-holder production to change in response to demand

Fish	Notes
Nutrients from other sub-systems in the farm are retained in fishpond sediments and water and can be used for crop production	Use of livestock wastes in fishponds may be the most practical way to reduce nutrient losses, especially N
Natural and stocked fish can harvest nutrients from common property for direct human food or use in livestock diets	Overgrazing of common land by ruminants may lead to deterioration, increased erosion and declining sustainability of the surrounding watershed or ecosystem
Efficiency of polycultures within aquatic systems in exploiting the range of aquatic niches. Control of livestock and human pests with an aquatic phase within the life cycle	Increasing diversity of livestock and fish may complement or compete within the farming system. Whereas increased amounts of monogastric waste are valuable for planktivorous fish, grass carp and ruminants may compete for limited amounts of grass
Maintenance of a water body necessary to raise fish improves the stability of water availability for the whole farming system	Livestock can be a contributing factor to destabilization, especially through deforestation, overstocking and soil erosion
Increased water and nutrient holding improves productive capacity around the pond. Sealing of pond traps nutrients and prevents loss to ground water	Fertile ponds may not contaminate groundwater significantly but more research is needed
Small individual size of fish often improves local marketability. Polyculture and perennial water increases opportunities for strategic marketing	Returns to labour are often attractive for livestock and fish production, and integration is particularly favourable. Integration reduces market risk and improves flexibility
Aquaculture systems are generally recent and are evolving rapidly around resources and markets. The dominance of small-holder compared to commercial production, and importance of aquaculture and fisheries as suppliers of fish, are major issues with policy implications	Concept coined by Pullin (1993) to describe the scope for future change of any system

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Sustainability viewed at a macro-level may include global, national, regional and watershed contexts. The expected dramatic increases in global trade following recent WTO agreements are expected to have wide ranging impacts on the nature of food production and viability of farming systems. Agribusiness is positive about the effects such measures will have on sustainability of food product (Box 1.D) but other groups fear a rapid undermining of poorer national economies and marginalization of small-holders with little market leverage.

Global trends in resource use for livestock and fish production, trade and consumption are important for understanding constraints at the farm, or even plot or pond level. One example of how macro and micro-level sustainability issues can interact, and be affected by institutions, is the changing basis of pig and fish production in the Red River Delta of Northern Viet Nam (Box 1.E)

Pig and poultry production using modern systems have been challenged as unsustainable in the long term on a global basis because of dependence on concentrates, which are based on non-renewable, fossil-fuels (Preston, 1990) Examples exist where modern systems, following 'shocks', have collapsed. These include oil exporting countries where oil price decline, and associated revenues made imported concentrates and poultry production uneconomic. Cuba saw major disruption in its imported, concentrate-based livestock industry as Soviet Union support was withdrawn and favourable terms of trade shifted. Even if concentrate feeds can be used economically, and the wastes productively reused for aquaculture, there may be inequities in the system that prove unsustainable in the longer term. Thus, an analysis of current systems using sustainability indicators can lead to the development of relevant research agendas. Given its complexity, some advocate the use of consensus indicators of sustainability in aquaculture production (Caffey and Kazmierczak, 1998)

The need for alternatives to the narrow range of feed ingredients used in most concentrates has been identified as urgent, especially for the tropics where little research has been conducted so far (Preston, 1990). In China, the substitution of semi-intensive aquaculture integrated within farming systems by intensive, feedlot production has been advocated on the grounds of improved productivity and reduced negative environmental impacts (Box 1.F). The analysis, though flawed, does identify a general tendency towards intensification of aquaculture. This may have particularly large impacts since intensive aquaculture is relatively more profligate than livestock in its use of feed resources and is more polluting. The major species raised intensively (salmonids and shrimp) are fed diets high in fishmeal (Naylor *et al.*, 1999) and often have large impacts on the local environment. Potentially the intensification of semi-intensive culture of carps

BOX 1.D

Agribusiness view on sustainability

It is generally accepted that intensification of livestock and fish production is required as low production levels do not meet people's needs. The major issue is the level of intensification that can support overall sustainable development.

The feed and pharmaceutical industries make the following claims:

Aspects of intensification that support sustainable development:

- **intensive agriculture allows livelihoods to be sustained through increased production to satisfy needs, without the need to further encroach on the natural environment with losses to biodiversity;**
- **removal of political and trade barriers that artificially support agriculture and lead to expensive surpluses;**
- **high yield agriculture can protect the environment by reducing soil erosion e.g. use of minimum tillage, intensified ruminant production can reduce greenhouse gases, and**
- **without veterinary medicines, livestock in Europe would need to increase from between 25 percent to 89 percent to maintain existing production levels.**

BOX 1.E

Challenges to sustainable farming in the Red River Delta, Viet Nam

In this region of historically high population density, both traditional farming systems and the 'green revolution' have failed to sustain livelihoods alone. Sustainable central and local level institutions have been critical to the maintenance of irrigation and flood prevention structures essential to maintain productivity in this area characterized by climatic perturbations[1]. Government policy changes towards a market system with increased availability of inorganic fertilizers, livestock feeds and breeds and fish farming systems are highly productive, use many external inputs and recycle intensively but recent studies indicate that sustainability is threatened by a declining capacity as soils become acidic[2]. Shortages of organic inputs, and excess inorganic fertilization, may exacerbate these problems. Traditional household pig production is valued for its role in asset accumulation and provision of organic manure for field crops. Certain developments may further undermine the sustainability of the system by reducing the availability of pig manure for application to the land:

- **Government policy change towards support for industrial pig production, leading to concentration of the national herd among fewer, larger producers, and**
- **increase in aquaculture leading to a demand for more inputs, including pig manure.**

Changes in demand are also occurring:

- **market for more and leaner pork, increasing demand for balanced feeds i.e. concentrates and modern strains of pig, and**
- **increase in demand for tilapia[3], which has become dominant in other parts of Asia where commercial, feedlot livestock–fish occurs.**

Source [1]Adger (1999), [2]Patanothai (1996), [3]Binh (1998)

an tilapias will have even greater impacts on the environment through raising demand for such feeds (Naylor *et al.*, 1999)

Difficulties in maintaining feeds or disposing of wastes will probably be only part of the problem of sustaining intensive livestock and fish systems on a macro-level scale. Control of pathogens may prove a more important constraint and pose greater threats to human populations (see 6.1.4). Densities of pigs exceed 9000 animals km^{-2} in parts of Western Europe as economies of scale and demand for cheap pork favour intensified production close to concentrated markets. The cost of disease epidemics such as classical swine fever, and the difficulties in their control at such levels of density, are prompting a rethink and new legislation (MacKenzie, 1998). Similar experiences are occurring with intensively raised fish such as the Atlantic salmon and black tiger shrimp. Control of pathogens through isolation is particularly problematic because of the need for water exchange in intensive systems.

High input, export driven agriculture (agronomy, animal husbandry and aquaculture) is more likely to be non-diverse (monoculture), highly extractive and polluting (little recycling) and unstable in the face of environmental change Moreover, its economic efficiency can be drastically affected by the vagaries of global markets. Smaller livestock units spread more evenly, based on local production of feeds and disposal of wastes, are likely to improve the sustainability of the livestock and associated farming systems.

Intensification is important, however, to ensure that smaller scale systems are economically viable and sustainable. Improvements in productivity at the local level have also been shown to be important globally. Low productive ruminants have been implicated in the increase in greenhouse gases, which could undermine sustained food production worldwide (see 4.2.1).

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BOX 1.F

A decline in integrated farming in China?

Rapid increases in production of cultured freshwater fish have occurred in China since 1985-86, the time of the Chen *et al.*, study[1]. Economic growth both created demand and the resource base to support an estimated 400 percent increase in production between 1985 and 1995. It has been estimated that by 1996, 40 percent of total production was based on 'aquafeeds', complete and incomplete feeds from small and large feed mills[2]. This infers that the other 60 percent (6.56 tonnes) were still dependent on 'no inputs' or 'organic farming'. This level of production is nearly 250 percent of that recorded in 1985, suggesting that integrated farming, far from being redundant, has expanded massively.

Since these systems are based primarily on waste from livestock production, which has also soared, any reduction in recycling in fish culture might further impact the wider environment that is rapidly deteriorating. Although aquaculture itself is acknowledged as partly responsible for the general decline in surface water quality that threatens further expansion, they[2] suggest that traditional manure-based integrated systems are the 'most significant' contributors. This is at odds with any other comparison of nutrient accounting which conclude that in semi-intensive pond culture, most nutrients are retained within sediments that can be removed occasionally and utilized locally[3].

The expected rate of pond expansion[2] (1-3 percent annually) suggests that even as availability of improved feeds encourages intensification, semi-intensive practices will dominate in the foreseeable future. Lack of self-sufficiency in food grains and protein concentrate could moderate tendencies towards intensive, feed-only based fish culture systems in China. Demand for 'fed' fish species is increasing rapidly but of the major species in the category tilapia, as a filter feeder, is known to be very cost effectively raised through fertilization and feeding[4]. Filter feeding carps still represent 38 percent of total production and registered an annual increase of 13 percent in 1996[2]. These levels of growth are more sustainable than those recorded for high priced luxury species (>40-80 percent year^{-1}) such as eels and turtles for which markets are quickly saturated and production costs highly sensitive to imported feed ingredients.

Source [1]Chen *et al* (1994), [2]Cremer *et al* (1999) [3]Edwards (1993) [4]Diana *et al* (1996)

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2 Evolutionary Development of Integrated Livestock–Fish Farming Systems in Asia

Understanding how farming households meet their needs is essential to assess the likely adoption of fish culture. A study of the evolutionary development of farming systems provides a useful framework since the nature and intensity of farming activities may indicate the likelihood of fish culture being appropriate. We analyse the factors that have stimulated intensification of farming and relate this to prospects for integration of livestock and fish production. Agricultural development has been linked to the pressures of human population growth and we also examine this effect, together with the impacts of changes caused by urbanization and industrialization.

2.1 Systems and scale

A schema of the possible evolutionary development of integrated farming systems is given in Figure 5. Settled agriculture is divided into three phases to indicate the potential role of integrated farming, particularly with respect to smallholder farmers in less developed countries (LDCs). Pastoral nomadism and shifting cultivation have limited aquaculture potential

Pastoral systems occur in arid regions in which seasonal availability of grazing limits carrying capacity of livestock and nomadism is a necessary part of a livelihood strategy. This movement of both pastoralists and shifting cultivators has necessarily constrained development of fish culture. The limited extent and duration of surface waters in arid regions also constrains natural fish production; and fish consumption is usually unimportant or absent among peoples living in such areas. Harvesting wild stocks generally remains important for aquatic foods after settled agriculture is well

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developed, whereas hunting and gathering terrestrial food declines rapidly as agriculture evolves

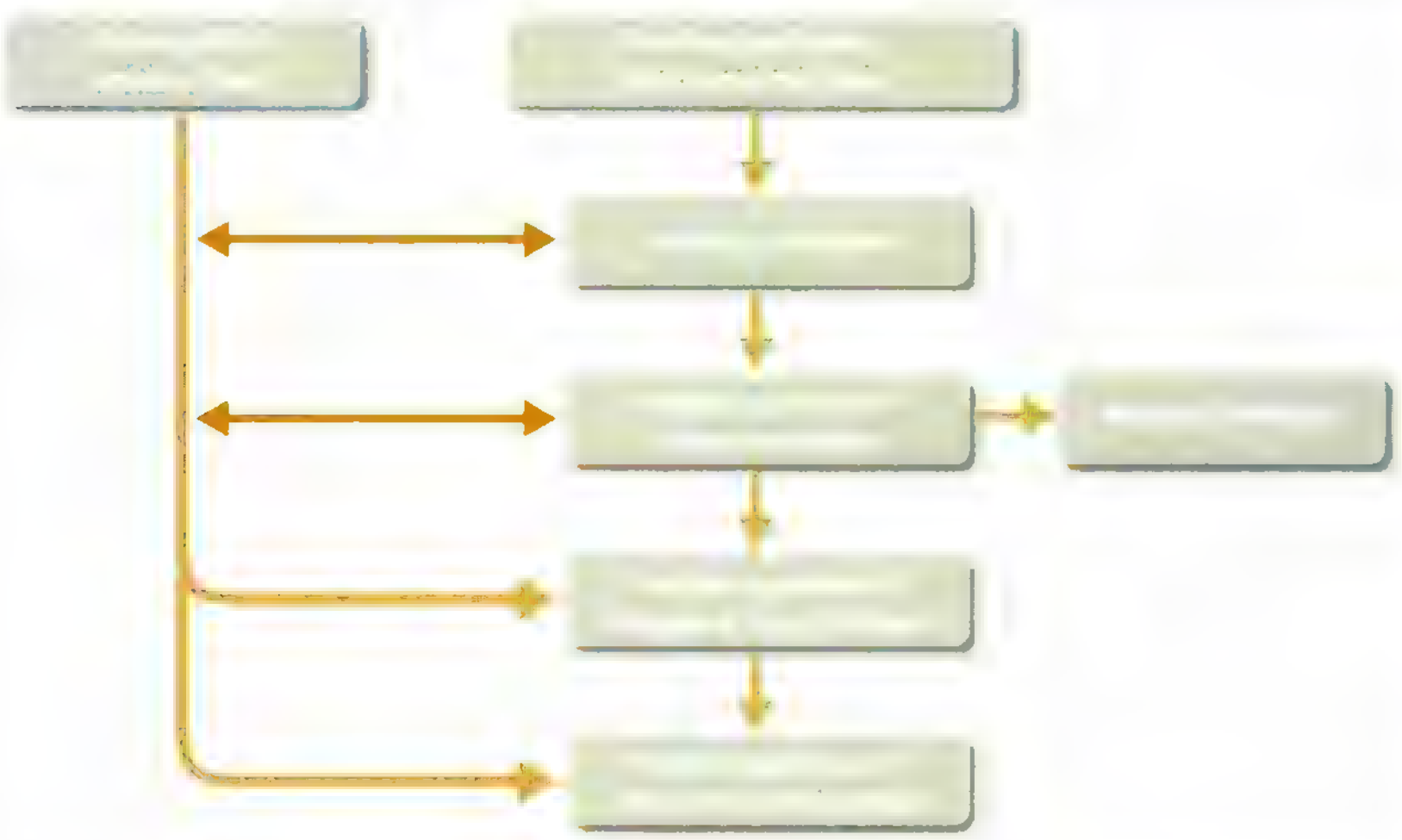
The evolutionary development of both livestock and fish production can be classified within a schema derived from the same broader farming systems context (Figure 6). Settled agriculture I is typical of many pre-industrial societies where there is little integration between crops and livestock managed principally for draught and to meet social obligations. If fish culture occurs it is normally at a very extensive level and closely associated with management of wild fish stocks. In settled agriculture II, the production of livestock and crops are more intimately linked, with livestock fed on crops and crop by-products and their manure essential for maintaining soil fertility. Use of N fixing plants together with other inputs such as nightsoil is also a common strategy for maintaining productivity. It is in this context that most traditional integrated fish culture is found. The trend towards industrial monoculture (settled agriculture 3) is a model followed by both livestock and fish production and is widely adopted in developed economies. Recently however, environmental concerns about heavy use of agrochemicals and waste disposal, consumer pressure and legislation are leading to some return to a more balanced approach to food production.

The tendency to develop more intensive farming systems that produce more food per unit area per unit time has traditionally been linked to increasing population pressure. Global population is expected to rise further from the current level of 6 billion, and may double before stabilizing, even at the most optimistic projections. Global population is split more or less equally between urban and rural areas but urban areas are expected to surpass rural area in population around the year 2005 and to account for 60 percent of the total by 2020 (UN, 2000)

Population pressure has not occurred, nor exerted its impact on intensification of food production evenly. Historically more fertile, well-

Box 5

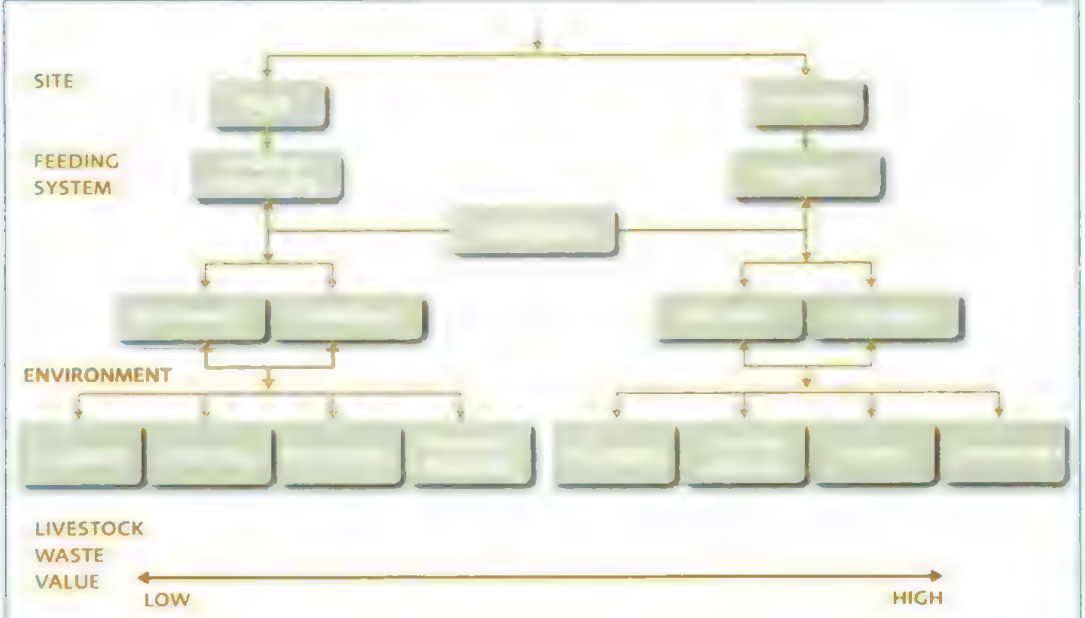
Evolutionary development of integrated farming systems.



Source: Modified after Edwards (1997)

Figure 6

Classification of livestock production and relationship to value of livestock waste for aquaculture



Source: Little and Edwards (1999)

watered environments have had greater productive potential and supported higher human populations. Thus, well-endowed floodplain agroecosystems in Asia have become the site of the most intensive traditional agricultural practices. Globalization of trade predating the colonial era, industrialization and major changes in human medicine have fundamentally de-linked food production and human population densities. If the concept of agro-climatic population, or the population in terms of food production capacity is used, today semi-arid zones are typically under much greater population pressure relative to land endowments than humid areas (Binswanger and Pingali, 1988). Although historically most of Africa has had little pressure on land resources, by 2025 the majority of the continent will comprise high-density countries requiring highly productive agricultural techniques.

Accelerating urbanization has stimulated demand for industrial food production in both developing and developed countries. Industrial food production requires intensive applications of resources, particularly energy, nutrients and water and is dependent on scientific knowledge. Farming operations spanning a wide range of intensity levels can be found increasingly within the same country although some doubt that coexistence of less intensive production systems with industrial methods is possible over the long term. Integration of livestock and fish, in which one or both sub-systems does not become entirely agro-industrially based, may better fit the limited resource base of smallholders and improve environmental sustainability.

Environmental effects

Environments have shaped cultures and dietary norms and taboos that in turn explains current

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distribution and dependence on livestock and fish. Recent anthropological research has shown that the concepts of the 'sacred' cow and 'abominable' pig have an environmental basis (Harris, 1997). The advantages of ruminants that digest cellulose and thus do not compete for food with humans, together with their more multipurpose attributes, are the bases for the cultural bias. The rejection of fish as food is also common among people in arid environments where surface water and natural stocks of aquatic animals are rare. The lack of large livestock in traditional slash and burn-based societies in Africa, and elsewhere, can be related to a low requirement for tillage, and their poor survival because of the tsetse fly (Binswanger and Pingali, 1988). Animal protein needs could be met by the harvest of game and wild fish and intensification of livestock and fish production was unnecessary (Little and Edwards, 1997) at the low human population densities found in typical swidden agricultural societies

If natural supplies of wild stocks are particularly rich, much higher population densities may be supported, provided human dietary energy needs are met. The rice-fish societies of lowland Asia are good examples of this situation where diets based on cultured, calorie-rich rice were balanced by diverse, aquatic plant and animal food gathered from the floodplains. Indeed, whilst natural fish supplies remain adequate, there is little interest in fish culture (Gregory and Guttman, 1996). Seasonal inundation of flood plains that led to dependence on aquatic-based food sources probably also limited the importance of livestock because of seasonal shortages of feed

In contrast, arid environments have stimulated pastoral systems in which low densities of ruminant livestock are grazed on extensive, common property pastures. The challenges associated with increasing productivity in such marginal, community-based resources systems are similar in both water-short, livestock-based pastures and water-rich, communally exploited wetlands. Major issues include how intensification can occur whilst safeguarding equity and the environment (Table 2.1).

Crop domination

In contrast to most shifting farming, in which livestock is relatively unimportant, or pastoralists in which livestock dominate, animals fulfil small but important roles within the household in settled agriculture. Furthermore, settled agriculture has much greater potential for aquaculture. Most land is reserved for crops and livestock are kept mainly for draught in settled agriculture phase I. Pigs and poultry may also be kept in small numbers, and usually scavenge and are fed wastes from the household. There is little integration between crops and livestock, largely because the number and nutritional status of the livestock are low. Ruminants depend mainly on limited rough grazing of harvested fields and common land. Limited crop diversity, as well as little recycling of crop residues and manures, are characteristics of crop-dominated systems. Such resource-poverty is typical of most small-scale farmers in developing countries today, except those that have leap-frogged to settled agriculture III through the green revolution. Crop-dominated systems include crops grown as the dietary staple such as rice and maize, often for subsistence, together with other crops grown for cash. Various levels of intensification may be evident e.g. irrigation, terracing, fertilization and weeding. Orchard crops and vegetables are often grown in home gardens

In some parts of the developing world, such as Southern Viet Nam, both livestock and fish are relatively important even in crop-dominated livelihoods (Ogle and Phuc, 1997) but the potential is far from realised by most households which rely mainly on wild fish. One survey indicated that farms in Central Thailand, which had diversified away from rice monoculture were more likely to use animal waste for fish culture than farms continuing to concentrate on rice production (Figure 7). Such intensification of livestock in settled agricultural phase I is often limited by poor feed availability. Also, draught animals tend to be used irregularly so although their productivity is low, farmers have little

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TABLE **2.1**

Comparison of common property management and scope for intensification in water-scarce and flood-prone environments

Characteristic	Environment: Water-scarce	Environment: Flood-prone	Notes
Dominant livelihood strategy	• Pastoral ruminant production	• Aquatic food harvest	
Density and yield area^{-1}	• Low	• Low	
Stock and habitat enhancement	• Disease control • Improved water availability • Selective feeding	• Maintenance/ enhancement of habitats • Stocking of juveniles	• High demand for indigenous species
Indigenous species	• Largely replaced but interest in return to ranching	• Typically still dominate though increasingly small, low value species	
Challenges to sustainability	• Overstocking • Range degradation	• Over-exploitation • Siltation • Irrigation structures and management	
Challenges to equity	• Herd accumulation by richer individuals	• Water extraction for surrounding agriculture including aquaculture by richer individuals • Intensification results in lack of access for the poor	

interest in improving their performance. Parallel development of intensive feedlot operations may also reduce opportunities for small-scale pig and poultry production (Little, 1995).

Widespread adoption of fish culture may not have occurred within crop-dominated systems, even when fish are valued and consumed. Stocks of wild fish may remain at a level that satisfy rural peoples' needs. Poorly developed on-farm water storage, or a lack of seed or knowledge may also constrain adoption. Traditional aquaculture in the valleys of upland areas of Indochina and Southern China, where population densities are high and wild fish stocks are very limited, suggest that aquaculture can evolve under these conditions, but that linkages between livestock and fish were relatively weak. Intensification of fish production based on animal manures would be constrained by the limited numbers of livestock and

BOX 2.A

Disease constrains livestock production

Aquaculture is a recent development among certain ethnic minorities, such as the Hmong in upland areas of Indochina, for whom pig production is both traditional and important. Under current conditions disease is a greater constraint to expansion of pig production than feed availability; more arrowroot or cassava can be grown, or vegetables and banana stems cut from the forest, if supplies of maize are limited. Pig wastes are used extensively, with wastewater directed towards opium-poppy growing plots, but the siting of pens over fish ponds has been adopted by some households.

Source Oparaocha (1997)

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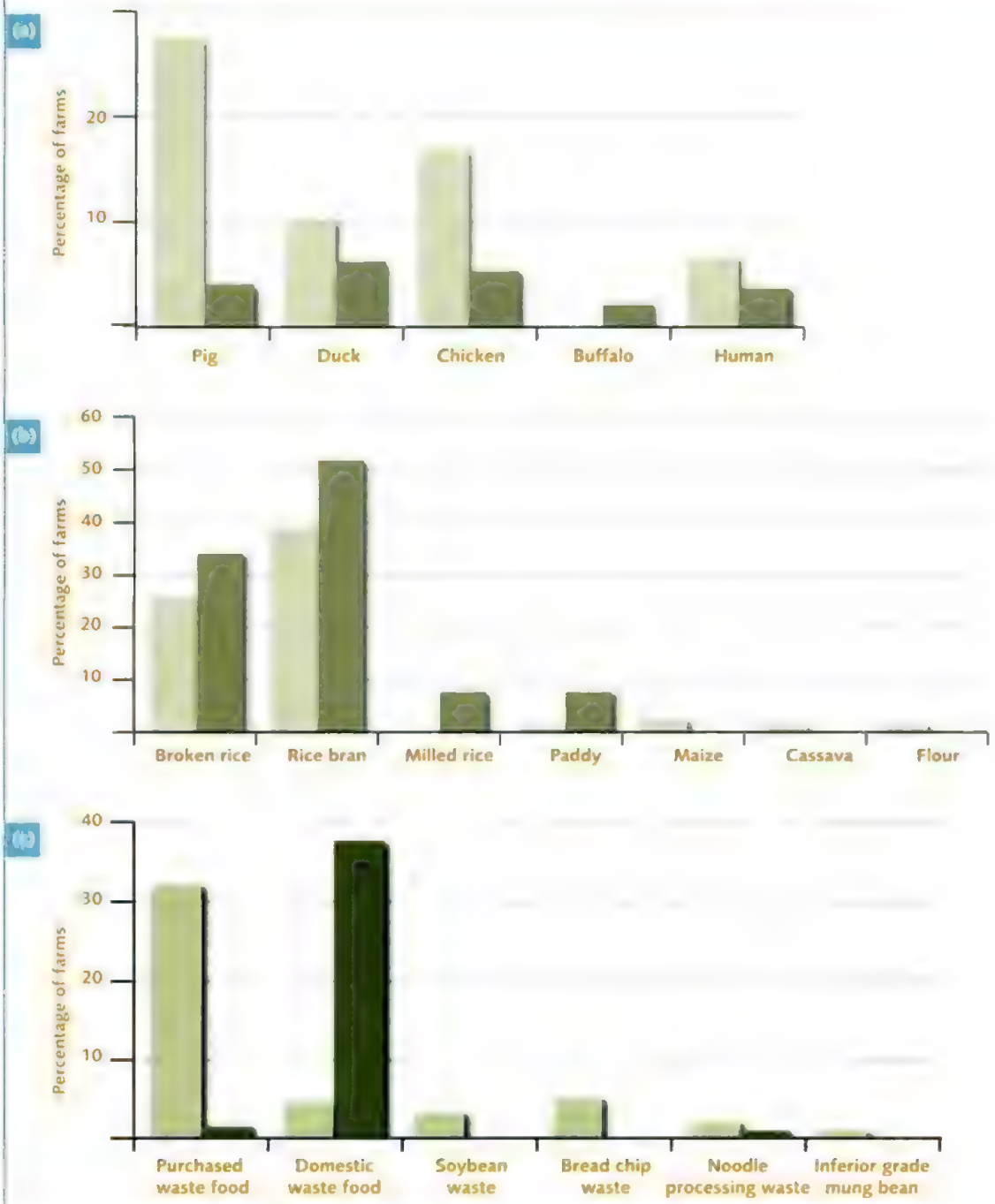
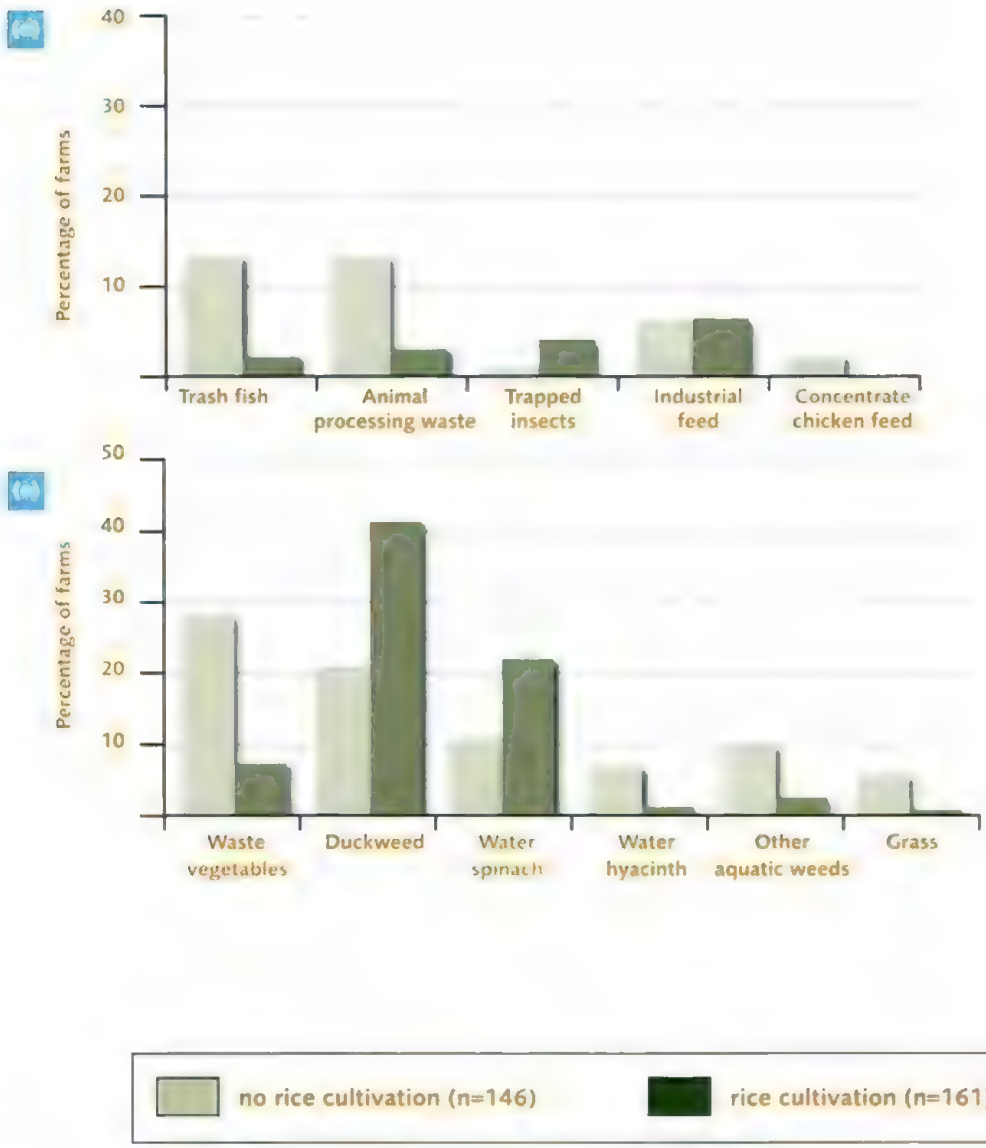
FIGURE 7

Percentage of farms in Central Thailand using various fertilizer and supplementary feed inputs for fish agro-industry (d) animal by-products and animal feed (e) vegetable matter.



culture (a) manure (b) rice and grain products (c) waste food from human consumption and



Source: AIT (1983)

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feed such as paddy grain or ricebran, are common in Asia

difficulties in collection and use of their waste. Livestock diseases also constrain inventories of livestock in many instances (Box 2.A)

Integrated crop/livestock

The integration of livestock with crops, or mixed farming, is the major characteristic of settled agriculture phase II. Livestock fed arable crops and improved pasture produced on the farm is the main focus. Crops are intimately integrated with livestock as manures are used to maintain soil fertility together with N fixing legumes Much of the farming in Western Europe and Eastern USA was of this type between 1850-1945 However, the recent increased control of nutrient effluents has begun to favour this form of farming again over industrial monoculture

The origins of mixed farming lie in increased demand for livestock products from urban centres. Various methods were adopted to increase livestock such as production and feeding of turnips to livestock during the winter and the rotation of cereal crops with legumes such as clover. More inputs such as nightsoil from urban centres, followed by inorganic fertilizers and feed concentrates, increased livestock densities and soil fertility

Integration of fish culture into farming systems has developed in areas where ponds were essential to diversification of rice-dominant systems and livestock were relatively few and feed limited. This has occurred in flood-prone areas, often where rice yields were low (Ruddle and Zhong, 1988) and land was raised to make dikes for planting perennial or upland crops Increasingly, buildings and roads are constructed on raised dikes and fill is obtained from borrow pits. The ponds excavated often serve primarily for storing water on-farm. Expansion of on-farm reservoirs (OFRs) has also expanded in areas in which drought otherwise constrained any intensification of cropping

Analysis of traditional integration of fish production within the highly diversified farms in the Zhujiang Delta, Southern China, indicates that wastes from livestock (pigs, silkworms) and

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people were important inputs. Fish production, however, was mainly based on the feeding of wild, uncultivated grasses for the macrophagous grass carp. This fish species largely filled the niche occupied by ruminants in mixed farming systems in Europe. Recently other macrophagous fish species such as the silver barb have been promoted to utilise seasonally abundant duckweed in Bangladesh (Morrice, 1998). The feeding of leafy vegetable material is traditional for raising macrophagous giant gourami in Indonesia, and potential exists for similar systems elsewhere based on herbivorous tilapias and *Colossoma* spp.

The major constraint to fish culture within farming systems based on leafy vegetation is the availability of adequate amounts to meet the needs of growing fish. Constraints to, and opportunities for, intensification of macrophagous fish production are similar to ruminants (Box 2.B). Opportunistic use of crop harvest by-products would not normally provide consistent levels of feed or feed quality. Continuous cropping of arable crops, e.g. cassava leaves has trade-offs in terms of the main crop yield. The use of arable weeds from intensive horticulture has unrealised potential in some situations (Moody, 1995) but would normally be constrained by irregularity of supply. Where such products are available, there will usually be competition with livestock.

BOX 2.B

Intensification of ruminant and macrophagous fish have similar constraints

- **Consistent quality and quantity of green fodder required to match needs of growing stock**
- **Seasonality of availability**
- **Harvest by-products often useful only as an occasional supplement**
- **Trade-offs in regular harvest of green leaves from growing crops**
- **Development of 'cut and carry', in which intensively grown vegetation that can be cut regularly and grows back rapidly, is a major step and requires significant land and labour resources**
- **Key factor is the value of livestock and fish products relative to resources such as land and labour**

2.6 Industrial monoculture

Many 'modern' settled agricultural farms stages I and II have intensified production by adopting some aspects of the scientific-industrial revolution'. Industrial monoculture (settled agriculture phase III) has evolved to supply ever larger, more concentrated markets with homogenous products. Increasingly dependent on the fruits of science and engineering, traditional mixed farming has changed over the last fifty years, using a greater range and volume of inputs. Improved varieties, agricultural chemicals, feeds and mechanization are used to produce fewer products in greater volume; many farm operations have become monocultures. The technical complexity and economies of scale characteristic of industrial agriculture encourage this tendency. In most cases the ready availability and low cost of industrial nutrients has reduced the need for integrating crop and livestock production. Industrial aquaculture, often of carnivorous species, evolved from using local surpluses of trash fish of little value to fatten wild fish and there were few links with land-based agriculture

Two important reasons suggest that industrial monoculture will evolve towards greater integration with other food production. Firstly, the real costs of adverse environmental impacts of specialized production are now becoming clear and closer integration can reduce or eliminate them. Secondly, wastes from intensive animal production can be valuable inputs into other parts of the farming system

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Apart from maintaining soil structure in arable systems, these include their direct and indirect use in fish production.

In parts of Asia where concepts of waste recycling are traditional and well understood, the industrialization of agriculture and changing demand are both challenging and opening new possibilities for integration. On the one hand integrated livestock–fish systems are evolving in China to rely increasingly on wastes from non-traditional livestock such as dairy cows and broiler chickens. Livestock wastes are also being used for a greater range of purposes; mushroom, maggot or earthworm production may be more profitable than aquaculture (Wang, 1994). However, rapid industrialization and moves towards intensive aquaculture practices can also undermine traditional integrated practices and threaten ecological stability.

3

Major Types of Integrated Systems in Asia

The role of livestock in the intensive, rice-based farming systems on the major floodplains of China, where aquaculture first developed, was fairly minor and linkages between fish and livestock production correspondingly weak. Applying the principles of waste recycling was, however, integral to sustaining China's high population densities. In recent decades, as the importance and concentration of livestock and their wastes have increased, these ideas have been applied more widely in China and elsewhere in Asia to reuse livestock waste for fish production. A range of experience and systems now exist.

The growth in production of monogastric livestock and agribusiness concerns has had a major impact on availability of waste for aquaculture. It has also changed the manner in which livestock are raised and marketed. Lower priced livestock products are the result but most are produced by entrepreneurs. Small-holder farmers have often benefited least.

Attempts to scale-down commercial livestock–fish systems for resource-poorer farmers have been uneven because of difficulties of access to, and management of, inputs such as feed and outputs. Alternative livestock systems that produce waste suitable for fish culture are still largely undeveloped. Typical smallholder, ruminant and monogastric production is extensive, making wastes difficult to collect and use. The wastes from poorly fed animals are often low quality. Upgrading such livestock systems can increase the potential for integration with fish culture. Strategic intensification and integration of livestock and fish are alternative paradigms to the conventional models of agribusiness development. Improved efficiency of nutrient use under conditions of nutrient scarcity can be a major benefit of integration. Least-cost production techniques that depend on using several different fertilizers and feeds,

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rather than a single high-cost compounded feed, is a relevant strategy for both livestock and fish production.

Commercial livestock production and processing typically produce nutrients in abundance, requiring cost-efficient disposal. This offers a different but equally important rationale for integration.

Current status

3.1.1 GENERAL CONSIDERATIONS

Livestock–fish systems in which waste from animals continuously raised in a pen and fed complete feeds ('feedlot') are used as pond fertilizers are the most common type of integrated system outside China (Edwards, 1993). Important characteristics used to classify such systems include type of livestock and fish species and scale of operation. The degree of integration has already been raised in definitions of integrated farming (Chapter 1). Definitions can include whether the fish sub-system receives all the livestock wastes, if livestock waste is used as a single input or as part of a multiple-input system. Since fish production is closely linked to the quality and quantity of inputs, the nutritional value of specific livestock wastes, in fresh or processed form, is also an important descriptor.

The major types of livestock may be classified on their potential for integration with fish culture (Table 3.1). Most fish production data for culture systems fertilized with livestock manure are based on feedlot systems but wastes from animals raised in scavenging systems can also be used. Clearly the latter waste is less easy to collect than waste from animals confined continuously. Some livestock wastes are more acceptable than others; whereas poultry manure from broiler houses is easy to handle and is used widely in agriculture, pig manure is often less acceptable for logistic, religious or aesthetic reasons. This is also reflected in opportunity costs. These may be relatively high for dried poultry waste and low for pig and cattle slurry. Nutrient density is also an important factor as monogastric animals fed high-quality feeds tend to have manure that is more nutrient dense and valuable than ruminants, particularly those raised on nutrient-poor tropical volunteer vegetation

TABLE 3.1

Matrix of livestock waste qualities and suitability for use in aquaculture

	Factors increasing relative suitability for aquaculture				
Livestock type	**Collectability**	**Acceptability**	**Nutrient density**	**Low opportunity cost**	**Lack of deleterious compounds**
Poultry					
Feedlot	•••	•••	•••	•	•••
Scavenging	•	••	••	••	••
Pigs					
Feedlot	•••	•	••	••	•••
Scavenging	•	•	•	••	••
Ruminants					
Feedlot	•••	••	••	••	••
Scavenging	•	••	•	••	•

(••• = high to • = low)

Source: Little and Satapornvanit (1997)

Some animal manures contain compounds that cause water quality problems, such as tannins and indigestible fractions. Waste from animals receiving poor nutrition, especially those on diets with high levels of fibre, is particularly unsuitable for fish culture. Other wastes may be contaminated with deleterious compounds such as pesticides, drugs or feed residues that have negative impacts on quality (Table 3.1).

Status

Most integrated livestock–fish systems described in the literature and operating successfully involve the use of manure from feedlot monogastrics. Pig and poultry manure is used fresh, or commonly for poultry, in a dried form for semi-intensive fish culture. Design criteria are given below (Chapter 5).

Pigs

Native varieties of pigs are well adapted to existing on roots, leafy vegetables, cereal by-products and household food waste (Livingstone and Fowler, 1984). Although they are not ruminants, fermentation in the hind gut is significant and this allows them to grow slowly on a poor diet. An important food item in some cultures is human waste, scavenging pigs playing an important role in nightsoil disposal.

In some cases intensification has been built around waste recycling. Traditional pig production in China was mainly for the production of manure (Ruddle and Zhong, 1988) as is still the case in northern Viet Nam. Weaned piglets are traditionally fattened on considerable quantities of grain by-products or root crops, especially sweet potato (*Ipomoea batatas*) supplemented with cultivated and volunteer green fodder. The number of animals raised is therefore related to the production and availability of these feeds, and the number raised per household is low. Pig manure was used to fertilize rice and vegetables, which may explain why the average fish yields in China were as low as only 2 tonnes. ha^{-1} until as recently as two decades ago, before more widespread introduction of feedlot livestock–fish integration

BOX 3.A

Case study of integrated farming in Central Thailand

In Pathum Thani, Central Thailand, a peri-urban area outside the main industrial belt at the time of the survey in 1980, there was a clear dichotomy of monogastric production systems. Farmers were more likely to have small flocks of chickens (>60 percent of farmers) or ducks (>30 percent) than pigs (<15 percent) (Figure 8).

Both the species and scale of production were found to affect the likelihood of their integration with fish culture in the province. Whereas farmers raising pigs were likely to integrate them with fish culture across a range of herd sizes, only farmers with large flocks of either ducks or chickens tended to use their waste for on-farm fish culture. Generally pig herds of less than 30 animals were less likely to be integrated with fish than those of more than 30. Pigs raised in large and small units were similar improved strains, fed and managed in feedlots. In contrast, large flocks of poultry, which were confined throughout their short, well-fed lives, were improved strains and small flocks managed extensively tended to be local breeds.

Source: AIT (1983)

Fish culture in northern Viet Nam is similarly constrained by the competing use of pig manure to fertilize crops.

Poultry

Local breeds of poultry can thrive in environments with abundant natural feeds, which are often rich in calcium and animal protein. Ducks are particularly important in the flooded agroecosystems of South Kalimantan and Southern Viet Nam, and in Java where irrigation supports year-round, paddy rice production. Management has become more intensive in many cases. It involves the confinement of poultry (and pigs) for all or prolonged periods to ensure both adequate nutrition and production,

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Meat ducks herded through rice fields after harvest being transported for fattening on an integrated fish farm

and control damage that freely scavenging animals can inflict on crops.

Poultry are also raised in large numbers when local or seasonal food surpluses occur. An abundance of aquatic snails from the lake allowed duck producers to intensify balut duck egg production in Laguna, Philippines, before feed mill-based feeds were available. Meat ducks are purchased and raised for short periods in large quantities to grow on dropped grain in ricefields after the rice harvest in Central Thailand during which time there is little opportunity for waste collection. But prior to slaughter the ducks are fattened intensively at high density producing large amounts of high quality, easily collected waste that is used for fish culture.

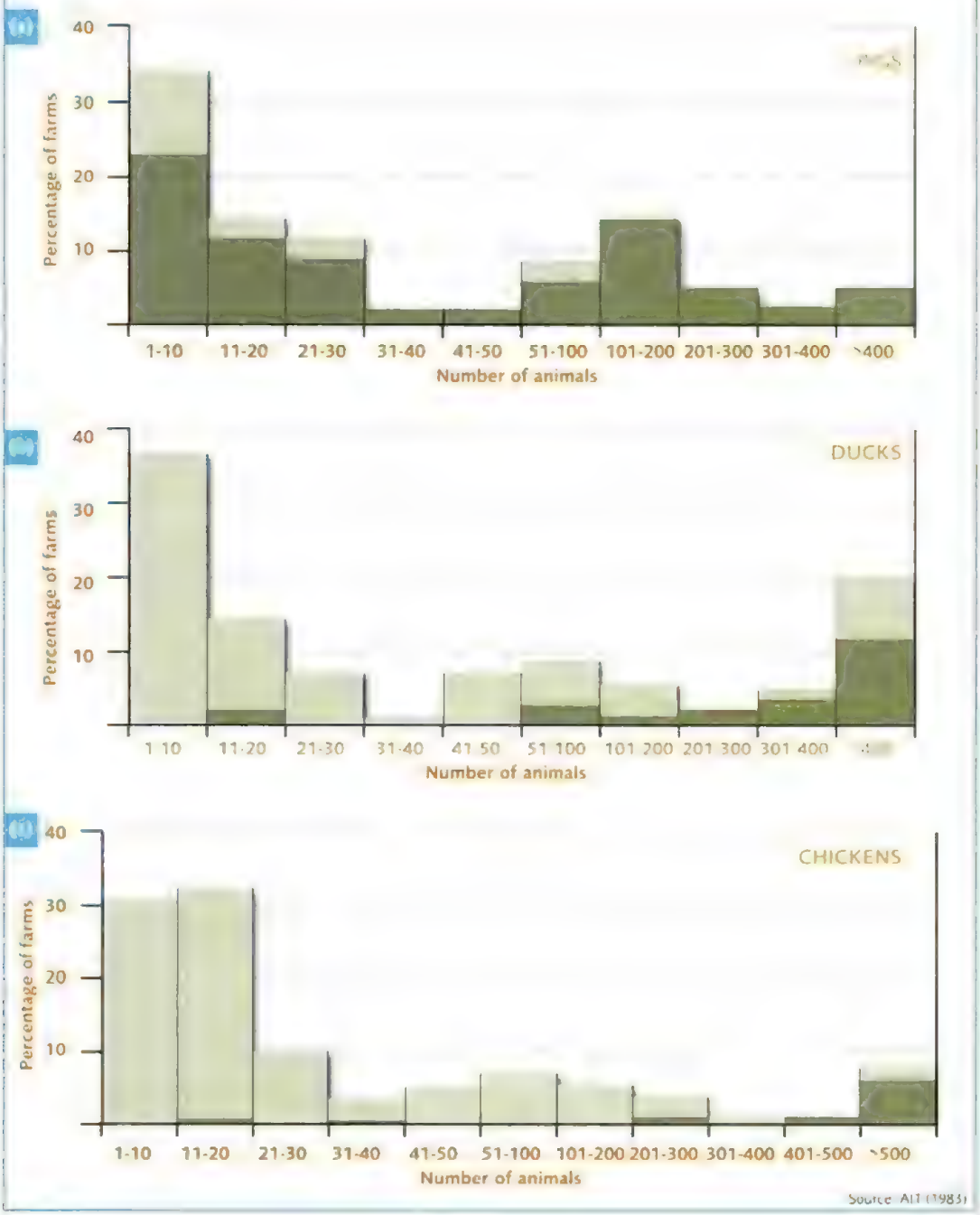
Failure of scaled-down modern systems integrated with aquaculture

Small-scale, feedlot monogastric-fish systems have been shown to be technically viable in on-station and researcher-managed, on-farm trials. However sustained adoption of these types of systems by farmers has been rare. Almost all research has been carried out using waste from 'improved' livestock systems, typically feedlot production of pigs and poultry. Such research has normally been carried out without participation of farmers in the design stage and, often, with financial incentives to encourage collaboration.

The normal criteria used for assessment of viability are positive internal rates of return or return to labour or capital. However, these are not holistic enough indicators, given the complexity of small-scale farmers' livelihoods. Resource-poor farmers have great difficulty sustaining even scaled-down, feedlot integrated systems. In Thailand it was found that production costs, particularly feed costs were high and there were problems in both securing inputs and marketing produce in rural areas. In effect, integration of feedlot livestock and fish for most small-scale farmers is a 'technological mismatch' (Edwards, 1998). A recent review of similar, small-scale, egg duck production systems in the same region found that with improved infrastructure, access to feeds and markets had improved. However, farmers still tended to either extensify production by reducing feed concentrate and allowing daytime scavenging or consolidate larger flocks to ensure viable returns (Box 3 B).

FIGURE 8

Livestock present ( ) and integrated ( ) on fish farms in Central Thailand by type and number of livestock.



Source: AIT (1983)

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Small is a relative term for both fish and livestock production. A profitable layer chicken-fish system was described in one area of Northeast Thailand (Engle and Skladany, 1992). Although farm size was within the norm for the region, operations tended to be irrigated and highly capitalized compared with typical, rain-fed farms in the same area. The concentration of operations close to a provincial urban centre also favoured the provision of cost-effective inputs and sale of produce, and the scale of operations was advantageous to both farmers and middlemen (Engle and Skladany, 1992)

The introduction of new types of livestock without consideration of markets has been another cause of failure in livestock–fish systems Cattle and broiler chicken production were 'stand-alone' enterprises in Panama *before* fishponds were introduced, whereas pigs and ducks were introduced with the fish (Lovshin *et al.*, 2000). The latter subsequently suffered marketing problems because of low demand, which consequently had an inverse impact on fish yields as there were insufficient livestock to fertilize the ponds. Similar problems have been reported in various African countries where meat

BOX 3.8

Constraints to integration of traditional livestock and fish production

The small size of backyard poultry flocks confined overnight for manure collection limits their impact in even a small fishpond. Moreover, variations in flock size and structure greatly affect actual waste availability through the year. Increasing flock size so that more waste is available for fertilizing fishponds requires improved availability of supplementary feed and a reduction in mortalities, particularly among young poultry.

The sustainability of traditional livestock production, especially of pigs and poultry that require grain and/or grain by-products is sensitive to the availability of these inputs and markets. Commercial, vertical integration of feedlot livestock using improved breeds and formulated feeds, whilst leading to opportunities for large-scale feedlot livestock–fish culture, may compete for the feeds and markets of backyard pig and poultry producers, reducing their economic viability.

Traditional management of monogastrics has relied on their ability to scavenge food from around the household and the wider environment. Generally, although local strains of livestock produce less meat or eggs from the same quantities of feed than modern breeds, they can survive and convert the poorer quality and variable quantities of supplementary feed typically available to smallholders. However, the practical difficulties of collecting wastes from unconfined animals and the lower quantities and quality of manures produced, has constrained attempts to integrate such systems with aquaculture.

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Golden Apple snail (*Pomacea canaliculata*) is a pest in rice fields in the Asian region but has been used as feed for poultry, pigs and catfish

ducks were introduced specifically to provide manure to fertilize fishponds without due attention to the wider system

Ruminant faecal waste is probably the most commonly used fish pond input in developing countries. In addition to its use in fish culture being limited by competition as a crop fertilizer or fuel, it has an inherent poor quality as a pond input. Wastes from unimproved grazing animals may be too poor in quality to produce acceptable fish yields in small ponds. In an on-farm trial, around 4 tonnes of fresh ruminant manure had to be collected and used to produce only about 20 kg of fish in a backyard 200 m^2 pond (Shevgoor *et al.*, 1994). The buffalo manure had low N and P contents and also contained tannins which stained pond water brown, further limiting phytoplankton growth due to reduced light penetration into the water column. Tannins are also known to be toxic to tilapias (Saha and Kaviraj, 1996)

A further major constraint is the collection and transport of low-value, bulky ruminant manures. Fish culture, however, may be integrated with traditional livestock management practices through linking the needs of livestock for watering, wallowing or overnight corralling. The need to handle and move bulky ruminant manure may thus be negated by strategic husbandry practices. Communal or individually-owned water bodies designed to allow the walk-in entry of large ruminants without physical destruction of embankments can allow low-cost ruminant waste input as well as conservation and concentration of nutrients from the watershed as a whole. Temporary overnight corralling and/or midday wallowing for water buffaloes in small areas may further concentrate wastes. Farmers can therefore 'harvest' nutrients from their own and others livestock at little cost. The relationship between herders and crop growers in West Africa in which livestock are rented to deposit dung overnight in an area to be planted to crops gives a working example how manure could be managed in fish culture. In Northwest Bangladesh, the overnight tethering and supplementary feeding of cattle around the house allows drainage of urine into nearby borrow pits, enhancing the productivity of an important source of fish consumed by the household.

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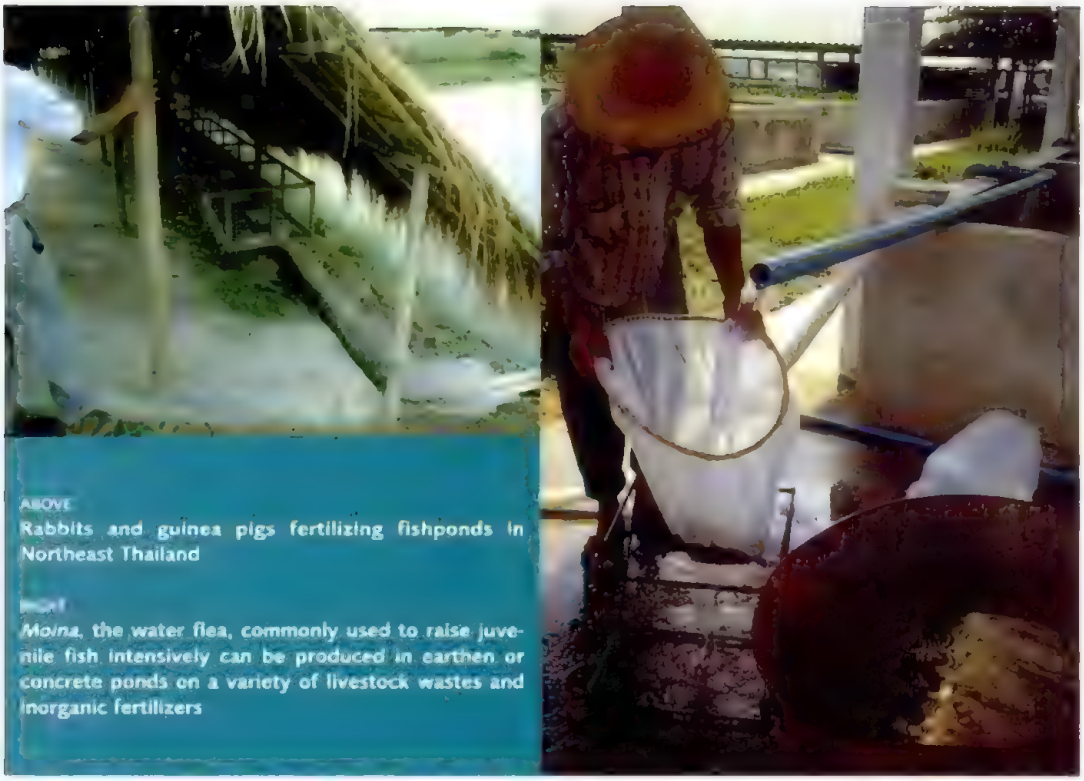

ABOVE
Rabbits and guinea pigs fertilizing fishponds in Northeast Thailand

RIGHT
***Moina*, the water flea, commonly used to raise juvenile fish intensively can be produced in earthen or concrete ponds on a variety of livestock wastes and inorganic fertilizers**

3.1.4 NON-CON

Non-conventional livestock encompasses both 'micro-livestock', a term coined for species that are inherently small and seldom considered in the broader picture of livestock development (NRC, 1991) and invertebrates, which may be produced as either direct food items for humans or constitute part of the diet of other livestock or fish. Over 40 multipurpose species with promise for smallholders were identified in an exercise involving 300 animal scientists in 80 countries. Many will produce wastes that can be readily collected because of their small size and confinement during production and are suitable for aquaculture.

Small individual size, and limited demands for food and space make micro-livestock increasingly attractive to resource-poor people. Micro-livestock, including both rare breeds of domesticated species and wild animals with potential for domestication, often retain local importance to small-holder families and have potential for larger markets, especially in cultures that value wild or bush meat.

Non-conventional livestock that can grow and reproduce on feeds that do not compete with human or other livestock are particularly interesting. Some invertebrates can be included in this category and are locally important as sources of food and fibre.

Pasture/crop by-product fed

These include geese and rabbits for direct human consumption; and silkworms which are mainly raised to produce high value, natural silk fibre. Geese and rabbits have played important roles in small-holder systems in which pasture and field crop by-products are available. Silkworms have been an important component of small-scale farms in parts of Asia for millennia.

The high intake, poor digestion strategy of geese means that their manures would probably function in a similar way to that of the grass carp in fishponds. In contrast, the copraphagy of

the rabbit may reduce nutrient levels of their manure; rabbit manure, however, is widely prized as a fertilizer and has been found to be a useful fish pond input in Africa (Breine *et al.*, 1996).

Woody waste

Termites are some of the most commonly used feeds in recently developed smallholders fishponds in parts of Southeast Asia. However, unsustainable harvesting of wild mounds normally quickly eliminates this potentially important food source as its rate of regeneration is usually far too low to permit even medium term use. However in Ghana, harvesting of termites for poultry is carried out sustainably by placing moist cow dung over termite nests shielded with tins. The termites burrow into the dung and some can then be fed to the chickens daily (NRC, 1991). Although actual quantities are small, termites are high quality feeds for a range of fish species and poultry. Where woody waste is produced in large amounts, their controlled production is a possibility.

Upgrading traditional livestock systems for aquaculture

Changes in traditional livestock systems have direct implications for peoples' welfare, biodiversity and the wider environment. The place of livestock within farming systems has always been dynamic and, particularly in marginal environments, reflected the resource base. Intensification of animal production has often been a critical part of improving rural livelihoods generally and a key issue is whether upgrading of livestock can become a key part in promotion of rural aquaculture.

'Upgrading' suggests an increase in productivity and importance of the animal within the farmer's system; normally genetic and management changes may constitute upgrading. Changes in germplasm alone rarely support long-term change.

Smallholder producers several by-products that can be used as inputs for aquaculture

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BOX 3.C

Key indicators of the potential for upgrading

- **Can the resource base support improved feeds and feeding strategies?**
- **What consequences do new, on-farm feeds have for the current farming system?**
- **Do introduced strains thrive under the production conditions?**
- **What are the consequences for maintaining animal health? Is veterinary support available?**
- **What is the likely demand for more animal products with the same or different characterisitics?**
- **Will upgrading management allow waste collection and use in aquaculture and does this negatively impact on current methods?**
- **What are the disadvantages and risks inherent with 'upgrading'?**

3.2.1 UPGRADING LIVESTOCK DIETS AND PRODUCTION SYSTEMS

The upgrading of livestock systems in developing countries has often resulted in a total loss of traditional breeds and management methods. A focus on improving yields rather than meeting the needs of the farmers and consumers has often been counterproductive in Least Developed Countries. Typically efforts have been made to develop a modern poultry industry in parts of Africa, whilst smallholder production has been largely ignored. However, improved management, disease control and strategic supplementary feeding can vastly improve productivity (Box 3.D)

Sometimes upgrading has occurred in response to markets or demand changes; the poorer meat quality and body shape/size hastened the decline of the indigenous *Mongkon* pig in Viet Nam despite their advantages in terms of tolerance to heat and low input diets. Farmers also prefer modern breeds because they grow faster whether fed traditionally, as in northern Viet Nam, or mainly on formulated feed in the south of the country. There has often been a failure to fully understand the complex role of traditional livestock production in rural livelihoods. After the purposeful destruction of the native creole pigs in Haiti because of fears of their possible role in transferring African swine fever to North America, modern breeds of pig failed to meet small-scale farmers' needs and a synthetic version of the traditional breed had to be 'reinvented' (MacKenzie, 1993)

Livestock systems, however, generally have to be improved in terms of the collection and quality of waste for productive integration with aquaculture. In practice, livestock manure from unimproved systems may be too small in quantity, too poor in quality, or simply unavailable because of competition from alternative uses, to be of relevance for aquaculture. Where livestock/crop interactions are already under threat, for example in Nepal, sustainability of crop yields are already dropping because of intensified practices and declines in livestock. In contrast, increased demand for milk and intensified cropping of a fodder crop rotated with cereals is leading to more livestock and greater sustainability in the Punjab (Fujisaka, 1995).

The quality and quantity of wastes are influenced by the diet and other factors (Chapter 5). The collectability of livestock wastes depends on feeding and housing arrangements. Clearly, waste can be collected more fully and efficiently in animals confined for all or most of the production cycle. However, larger numbers of animals raised more extensively, but confined for part of the production cycle, can also produce substantial quantities of waste. Moreover if quantity and quality of feed consumed during the period of grazing/scavenging are high, this is reflected in the quality of the waste.

Several factors mitigate against the ability of smallholders to increase number, confine and feed livestock enough to benefit from using their waste for fish culture. The limited ability of monogastrics to utilize diets high in fibre has reduced the scope of improvements to traditional

BOX 3.D

Upgrading scavenging poultry diets and management in Ethiopia

More than 60 percent of rural families in the Ethiopian highlands keep chickens and women own and manage the birds and control the cash from sales. Average egg production of scavenging hens is around 40 eggs bird^{-1} year^{-1}. In a trial with a women's group, it was found that improved housing and management such as provision of water, removal of eggs and prevention of broodiness improved production to over 100 eggs bird^{-1} year^{-1}. These results were obtained using the local strain of hen vaccinated against Newcastle disease. Supplementation with maize only, noug cake (a locally available protein-rich oil cake) only, or the two feeds combined increased yields to more than 200 eggs bird^{-1} year^{-1}. The highest production was obtained on the maize only diet, confirming that the scavenging chickens were limited more by lack of energy than by protein. This approach to upgrading scavenging chickens can increase the returns from this activity and, as both flock size and plane of nutrition is enhanced, increase the amount and quality of collectable wastes for aquaculture.

Source: Dessie and Ogle (1996)

systems of raising pigs and poultry. The number of monogastrics that could be raised has been linked to the availability of grains and/or root crops surplus to direct human consumption needs. The processing of staple foods such as maize and rice within the household has been a critical source of brans and broken grains suitable for feeding livestock in traditional systems. Commercialization of food production that leads to processing grain off-farm leads to losses in opportunities for small-scale livestock, unless a concomitant increase in fodder crop production occurs.

Recent research with farmers has identified promising strategies for breaking this dependence by using feed inputs available on-farm such as sugar cane as energy sources (Preston, 1990). High quality forages such as mulberry, hibiscus and cassava leaves can provide some or all of the protein needed in tropical livestock systems (FAO, 1999a) but for monogastrics suitable protein sources may ultimately constrain such systems (Kroeske, 1972). Soybean fodder and small fish have been used successfully for pig production in the few cases in which these are available. The ability of ducks to utilize low-fibrous plant material such as duckweed has also been shown.

Small-scale farmers may have a continued relative advantage in the production of ruminants and village poultry because of their forage-feeding base and special characteristics (taste, texture, 'organic' origin). Non-conventional livestock that can be reared to substitute for forest or bush meat may fill a similar niche that is expanding in many places where industrial food production is becoming the norm. In general, however, these systems must be upgraded to a level of productivity that meets the farmers' rising expectations. Clearly, some degree of intensification of livestock is necessary for any integration with fish culture to be sustainable. Market development and veterinary support, however, are often critical to the development of such improved systems.

3.2.2 COLLECTION OF MONOGASTRIC WASTES IN SMALL-HOLDER SYSTEMS

The adoption of semi-feedlot systems with controlled grazing/browsing for part of the day and confinement with supplementary feeding for the remainder of the day and night-time may have the greatest potential for upgrading livestock production and allowing integration with aquaculture by small-holders (Figure 6). This combines the low-risk advantages of traditional systems with enhanced productivity producing more and better quality livestock waste that can be collected for use in fish culture. Aquaculture can, therefore, become a focus for improving overall nutrient use on-farm. The nutrient-poor

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status of small-scale farms contrasts with the high losses of nutrients, particularly N, which occurs before collection and reuse. The N from backyard poultry waste and urine from ruminants is often almost completely lost. Whole-farm strategies that incorporate fish culture may enhance conservation and recycling of these nutrients, particularly if livestock are raised in improved, semi-feedlot systems. Such systems may also favour the strategic import and use of nutrients as feeds or fertilizers on to the farm. However, substantial and cost-effective improvements in productivity of the whole system probably require both better recycling and use of more inputs.

A major problem with upgrading scavenging poultry flocks to a size that their manure can have an impact on fish production is poor survival of starter birds, and poor availability and/or cost of supplementary feed for growing birds. The strategic use of higher quality feed for starters and use of alternative supplementary feed for adults can increase flock size, and quantities and qualities of waste available (Khalil, 1989). The adoption of heat stable vaccines to prevent Newcastle's disease has had a major impact in areas where available (Alders and Spradbrow, 2000). The collection of waste from scavenging poultry overnight is often possible even when they remain unconfined: roosting of birds over ponds can be encouraged with strategic feeding and placement of perches/cover. Manure can even be collected under tree branches or within housing by placing sheeting under roosting positions and feeding stations. The sheets, which can be old textile material or split fertilizer bags can then be washed or suspended in the fishpond.

Inadequate feeds and their poor utilization are key constraints to improved ruminant systems. The greater use of crop by-products, undergrowth of tree crops and improved fodders, particularly legumes, have been promoted to, and adopted by, farmers. The three strata forage system in which grasses and ground legumes (first stratum), shrub legumes (second stratum) and fodder tress (third stratum) allows good quality feed to be produced year-round in dryland farming areas of Bali (Devendra, 1995). The introduction of multi-tiered feeding and polyculture in these terrestrial agroecosystems is analogous to the multiple feed/space niches typical of fertilized fish ponds stocked with a polyculture of fish.

The use of supplementary concentrates such

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as neebran can further improve performance, especially of pregnant and lactating animals. The biggest challenge is to improve the feeding value of the large amounts of fibre (ligno-cellulose) available. The use of pretreatment using alkali or urea, which improves fibrous feed quality, has been promoted but is not widely adopted by farmers, except in China where it has been successful (FAO, 1997). Although the use of multi-nutritional blocks, providing nitrogen and micro-nutrients, are being used in several countries to improve the utilization of low quality feeds (Leng *et al.*, 1991), in practice their use is often constrained by their poor availability to farmers in rural areas (Peacock, 1996).

Improved feeding often develops with increased confinement of ruminants on small-scale farms in Asia. Animals that are stalled some or all of the time, and fed cut-and-carried forages and/or concentrates, tend to show increased productivity and produce wastes of higher quality and collectability (Chapter 5).

Both low nutrient density and high concentration of tannins negatively affect water quality and limit the amount of faecal wastes that can be used in fish culture. An optimal strategy under many conditions would be to use solid wastes to fertilize crops and to collect urine and washing water for fish culture. Normally, collection and retention of urine N in the farming system is problematic. Generally the urine simply soaks away or is absorbed by bedding and solid faecal waste. Use of greater quantities of bedding materials high in carbon (C), such as straw or stover, improves N conservation but these may be unavailable in the quantities required. Nitrogen is also lost or becomes refractory under such conditions (Anderson, 1987). Pens can be constructed with a thin sloping concrete floor to direct urine and washing water into a plastic bag

Above
Herding ducks in the Red River Delta. Overnight confinement and supplementary feeding allows collection of wastes for use in fish culture

Below
Washing a plastic sheet placed to collect manure and waste feed from scavenging ducks penned overnight

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Where concrete is unavailable, elevated wooden pens, which are often used for stalling small ruminants, can be sited directly over the pond. In practice, however, livestock are often penned away from the pond and waste has to be collected and carried. There is a need to develop practical methods to collect urine, perhaps using simple plastic sheeting and bags.

In many situations livestock wastes will be only one of several nutrient inputs used to raise fish. Livestock wastes may be too few, low quality or available irregularly. Multiple inputs are used in both subsistence and commercial fish culture with livestock waste to capitalise on an occasional or seasonal abundance of other wastes and by-products and to improve the overall balance of inputs into the pond.

The use of multiple inputs usually suggests that livestock production does not dominate fish economically. Use of livestock manure alone usually suggest that aquaculture is a relatively minor component of the overall system.

Smallholders

Various factors may limit the number of livestock that a farmer can manage and integrate with fish culture, reducing wastes to levels below optimum. Edwards *et al.* (1983) found that problems marketing duck eggs, and high feed costs, constrained small-scale farmers maintaining even 30 ducks over small ponds (200 m²) as feedlots. Farmers with limited numbers of poultry for their pond area need additional nutrient inputs to optimize productivity. Extension of multiple input systems can increase overall levels of inputs used by small-scale farmers, although often not to the levels considered optimal by researchers (Thu and Demaine, 1994; Ahmed *et al.*, 1995; AASP, 1996). In a project in Bangladesh the frequency of poultry waste used as pond inputs increased from only 3 percent of farmers to nearly 30 percent after extension (Table 3.2). Comparative figures for cattle manure, inorganic fertilizer and rice bran reflected higher initial use.

Supplementing low-nutrient density wastes from scavenging animals with other inputs is particularly common. Farmers in Udorn Thani, Thailand used a variety of inputs, in addition to livestock manures including a variety of plant leaves, and rice bran (AASP, 1996). The wastes collected from limited numbers of scavenging ducks fed a supplement at night can increase fish yields in systems fertilized inorganically by over 40 percent. Additionally, the overall efficiency of the limited ricebran used on the farm is improved and products diversified (Table 3.3). In small ponds, the relative amounts required are also affordable, given the value of the fish produced (Edwards, 1996).

TABLE 3.3

Use of wastes from ducks fed supplementary food, in addition to inorganic fertilization[d]

	Yield[b]		Food Conversion Ratio[c]
	Fish (kg)	Duck eggs (No.)	
Ducks only[a]	-	300	5.5
Fish only	45	-	-
Fish + Ducks	65	300	3.2

Source: Little and Edwards (1999)

[a] Duck wastes include all wastes (excreta plus waste feed)
[b] net fish yield for a 330 m² earthen pond over a 90-day period, extrapolated from fish growth in 5 m² tanks
[c] Food conversion ratio of fresh village ricebran to weight of eggs produced from [illegible]
[d] Inorganic fertilization at 3 kg nitrogen ha⁻¹day⁻¹, 1.5 kg phosphorous ha⁻¹day⁻¹

TABLE 3.2

Change in frequency of pond inputs before and after extension in Kapasia Thana, Gazipur District, Bangladesh

Input type	Percentage of households	
	Before	After
Cattle manure	66	100
Inorganic fertilizer	29	100
Rice bran	48	100
Poultry manure	3	29

Source: Modified after Ahmed and Saha (1996)

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Commercial systems

Commercial, integrated livestock–fish systems are best developed in countries such as China, Taiwan and Thailand where vertically integrated feed companies have exploited rapidly growing markets for meat and social, market and physical conditions are optimal for using the large amounts of waste through semi-intensive fish

BOX 3.E

Changing integrated systems in China

Complex, multiple input systems were typified by state and commune managed integrated farms in China during the 1980s (Edwards, 1982). These contrasted with traditional household systems in which fish yields were highly dependent on large quantities of green fodder consumed by grass carp, in addition to small amounts of pig and human waste. The dike-pond systems of the Zhujiang Delta were particularly complex involving multiple inputs, especially those relating to production of silkworms (Ruddle and Zhong, 1988). These systems, having reverted to household responsibility under the rural reforms in the late 1970s, have also been most affected by the drive to industrialization and urbanization in recent years.

Prevailing prices in the 1980s favoured a grass carp-dominated polyculture based on pasture grass fertilized with pig manure, which was more profitable than the direct use of pig manure in ponds stocked with filter feeding fish or feeding pellets. This reflected the lower price of filter feeding fish even then, compared to grass carp and low cost of labour. Feeds at this time were also relatively high priced, low quality and poorly suited for the mainly planktivorous species raised Yang *et al.* (1994).

Aquaculture has had a variable development in different regions in China but its traditional practice is associated with provinces to the south and east; in other areas, particularly in the north, aquaculture is relatively recent. It is therefore unsurprising that the level of intensification is uneven and Chen *et al.* (1995) analysis of practices by province gives a clear picture of emerging trends that have since become more apparent. Integration with livestock in the 1980s was of crucial importance to inland fish culture, with more than 80 percent of ponds receiving manure of some type (Table 3.4). The systems were characterized by the range of manures, and other inputs used. A trend towards specialization of livestock and fish production was evident as only 22 percent of farms raising fish were physically integrated with livestock at the time. The investment in feeds in the mid-1980s was already much more than fertilizers; all fertilizers together cost less than 8 percent of total nutrient costs. Farmers were also spending more on inorganic fertilizers (56 percent of total fertilizer cost) than manures (human 12 percent; pig/cattle 28 percent and poultry 4 percent).

High yielding systems used most high-quality feeds and grass and snails, and they also relatively more highly stocked with 'fed' fish, grass and black carps, and omnivorous fish. In lower input systems (and poorer provinces), filter feeding fish dominated and fertilizer use (Figure 9) was relatively more important. However, even in 'low' yielding systems, feed costs were 80 percent or more and fertilizer only 20 percent. Certain other differences were identified between provinces. In Hunan, a 'medium' level fish yielding but livestock-dense province, a majority of ponds had livestock physically integrated (73 percent), presumably as opportunity costs of the waste were low. Generally medium-yield fish farmers had the most livestock and were best diversified with respect to other sources of income. High yielding fish farms had intensified stock management, spent more on feed, fuel and equipment and specialized more in valuable fish species. They tended to raise fewer livestock and derive less of their income from off-farm labour. Less than 3 percent of fishponds were physically integrated with livestock suggesting greater specialization and the reduced value of livestock waste at a certain level of intensification of fish culture.

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TABLE **3.4**

Feed and fertilizer inputs in integrated systems for three areas with different levels of production in China

Input	Composition by weight (t ha^{-1} year^{-1})				Composition by cost (percent)			
	Low	Medium	High	Overall	Low	Medium	High	Overall
Feeds								
Grasses	20 91	35.24	59 65	44 53	22	18	18	18
High quality	3.09	3.95	12.18	8 06	45	37	63	58
Low quality	2 45	7 04	4 61	4 63	15	24	4	7
Pellet feed	1 04	2.43	3.34	2 57	18	21	9	11
Snails	0.00	0.03	16.55	8 71	0	0	7	5
Cost					1889	2112	6388	4303
Fertilizers								
Nightsoil	1.36	2.27	6 98	4.52	7	5	19	12
Livestock manure	7.91	14.47	8.23	9 57	33	20	32	28
Poultry manure	0.77	0 00	1.65	1 06	2	0	8	4
Total manure	10 04	16 74	16 86	15.15	42	26	59	44
Chemicals	0.84	1.93	0.53	0 92	58	74	41	56
Cost					359	520	298	364

Source Chen *et al* (1995)

culture. Increasingly these are complex, multi-input systems in which the use of formulated feeds, aeration and improved strains are being adopted to increase yields and returns. The evolution of integrated fish culture in China gives a particularly interesting profile of how heterogeneous conditions stimulate different practices. Several studies based on data in the 1980s do indicate some important trends in the country's transformation (Box 3.E).

In locations where market and physical conditions are suitable for both livestock and semi-intensive fish production and the concentration of livestock production lowers the opportunity cost of the wastes such as Chacheongsao and Nakon Pathom provinces near Bangkok in Thailand, direct physical integration of livestock and fish production develop as in livestock dense provinces of China Fluctuating livestock prices are common under such conditions and Edwards (1985) showed that fish production makes a significant contribution in covering losses when livestock prices are low

The trends towards simplification of integrated systems with single species of livestock raised at high density, and the use of supplementary feed and aeration has developed over the last two decades in China. There has also been substitution of livestock-fish integration with more feed-based, fish production and diversification to higher value species (Cremer *et al*., 1999). This appears to be mainly occurring in areas close to the major, richer markets where land is most limited, fish prices are high and high quality feeds are available. Nationally the situation still reflects dependence, and increased growth, on fish raised in fertilized ponds and it is clear that China will need to depend on integrated concepts to sustain inland aquaculture (Box 3.E)

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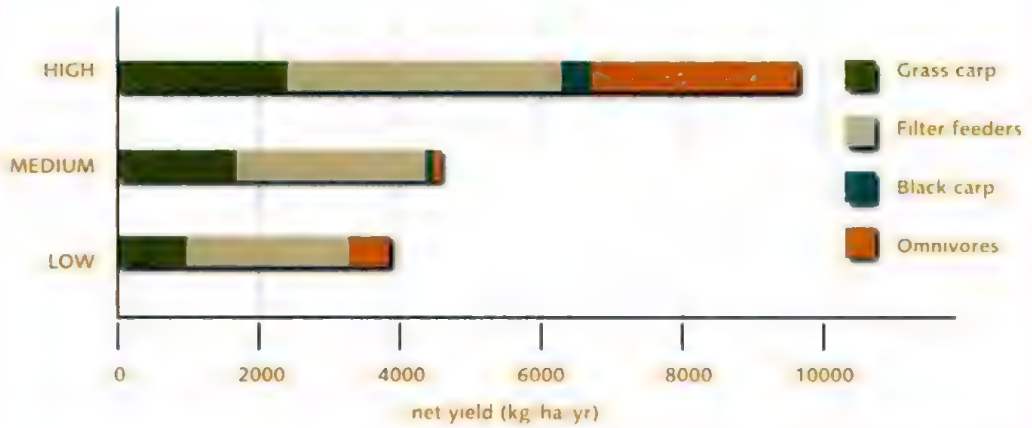
FIGURE 9

Percentage yield by fish species in three areas of productivity in China



Source: Modified from Chen *et al.* (1995)

Inorganic fertilization

Farmers with limited numbers of livestock may use fertilization based on both livestock wastes and inorganic fertilizers. Inorganic fertilizers may be a cheaper form of N and P than purchased livestock manure in many situations (Table 3.5), and highest yields may be achieved without, or with relatively low loadings of manures. This may be particularly the case for phytophagous fish such as Nile tilapia. In highly productive ponds fertilized with inorganics (4 kg N.ha^{-1} d^{-1}), there may be no significant benefit of including chicken manure in tilapia monocultures (Knud-Hansen *et al.*, 1993). Green *et al.* (1994) recorded similarly high yields (>20 kg. ha^{-1} d^{-1}) of Nile tilapia using higher levels of chicken manure in combination with inorganic fertilizers.

The benefits of using high levels of inorganics

TABLE 3.5

Economic comparison of different fertilizers with respect to available nitrogen (N), phosphorus (P), and carbon (C) (US$ = 25 Baht)

Fertilizer	Cost (Baht. 50 g^{-1})	Available N (Baht. kg^{-1})	Available P Baht. kg^{-1})	Available C (Baht. kg^{-1})
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Urea	240	10	-	24
TSP	450	-	45	-
$NaHCO_3$	1000	-	-	140

Source: Knud-Hansen *et al.* (1993)

a Wet weight.
b assumes 40 percent dry weight of total N is available (Knud-Hansen *et al.*, 1991).
c assumes 10 percent dry weight of total P is available (Knud-Hansen *et al.*, 1993)
d assumes 50 percent dry weight of organic C oxidizes to dissolved inorganic carbon (DIC)

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may be constrained by their availability or opportunity cost. Other species may benefit more from use of manures, especially when high levels of inorganic fertilization may be less appropriate such as for carp polycultures which include a detritivore. Supplementation of organic wastes in low-input, chemically fertilized ponds increased the growth rate of mrigal, the detritivorous Indian major carp compared to controls (AASP, 1996)

Supplementary feed

Supplementing limited livestock manure with direct feeding of fish is an alternative strategy The impact of supplementary feed on yields of fish in ponds fertilized with livestock waste is affected by many factors. The level of natural feed to some extent affects the efficiency with which fish utilize supplementary feed. More natural feed allows use of more high-energy supplements to 'spare' the protein requirements and support the growth of more fish (Chapter 5) The optimal levels for supplementary feeding are complicated by the variable levels of waste feed that are mixed with the manure which may be considerable. Purchasing supplementary feed for fish in livestock–fish systems may not be cost effective however, especially if feeding rates are high.

A reduction in feeding costs of more intensive systems by fertilizing ponds with livestock manure is another strategy that has attracted the attention of farmers and researchers alike. As feed cost typically comprises about 80 percent of operating costs of intensive aquaculture systems (Shang, 1981), any improvement in food conversion efficiency is desirable Clearly, the fish species raised need to be suitable for culture in waste-fed, plankton-rich systems. Green *et al* (1994) found that the tambaqui (*Colossoma macropomum*), in contrast to the Nile tilapia, grew poorly in fertilized systems without supplementary feed. Increased levels of inputs have consequences for overall loading rates, water quality and fish yields (Chapter 5).

Microphagous Nile tilapia fed pelleted feed in duck manured, mechanically aerated ponds in Taiwan yielded up to 18 tonnes ha^{-1} however (Liao and Chen, 1983) in systems that produced most of the low cost tilapia exported to the USA Hepher and Pruginin's (1981) description of

BOX 3.F

Summary of factors affecting use of inorganic fertilizer and feeds with livestock wastes

- **Are inorganic fertilizers available and will their opportunity cost affect their use by the farmers?**
- **Is the farmer raising mainly plankton-feeding fish, or species that feed in other niches within the pond?**
- **How expensive are inorganic and organic fertilizers when costs per unit of available nutrient are considered?**
- **What is the quality of wastes with which the feeds are being supplemented? Many 'wastes' contain spilled feed.**

  What is the economically optimum level of supplementary feeding for the type of waste-fed aquaculture being used?
- **Are supplementary feeds only profitable for nursing and fattening fish?**

commercial polycultures in Israel indicates that fertilization with livestock waste and inorganics was an essential component of high-yielding semi-intensive systems in that country Feeding only in the later stages of the culture period, when the nutritional needs of the fish exceed the level supported by natural feed alone may also reduce feed costs. Green *et al.* (1994) found that at densities of 1 fish m^{-2}, tilapia could be raised on poultry waste alone for the first 90 days of a 137 day production cycle without any differences in final yield.

3.3 Integration with agro-industry

3.3.1 GENERAL CONSIDERATIONS

Global market integration and commercialization greatly increase the volume of animal waste (de

Haan *et al.*, 1997). As incomes increase, a greater proportion of animals and animal products are processed. Large quantities of homogenous wastes produced during production and processing of feedlot livestock make for economic use of such by-products for fish feeds under a variety of conditions. Re-feeding manure and slaughterhouse waste back to livestock and fish has been common in recent history (Chapman, 1994). Early accounts of trout production indicate a dependence on old horses as fresh meat (Schaeperclaus, 1933) or as a substrate for maggots used as feeds (Rumsey, 1994). However, the use of meatmeals has come under increased scrutiny recently after ineffective processing of slaughter wastes led to outbreaks of bovine spongiform encephalitis (BSE) in cattle. Fish and shrimp meals are widely used as ingredients in both animal and fish feeds. Both livestock production wastes i.e. manure and slaughterhouse wastes (blood, bones and viscera) may be processed into conventional feed ingredients used by feed mills (Figure 10), although only the latter is widespread.

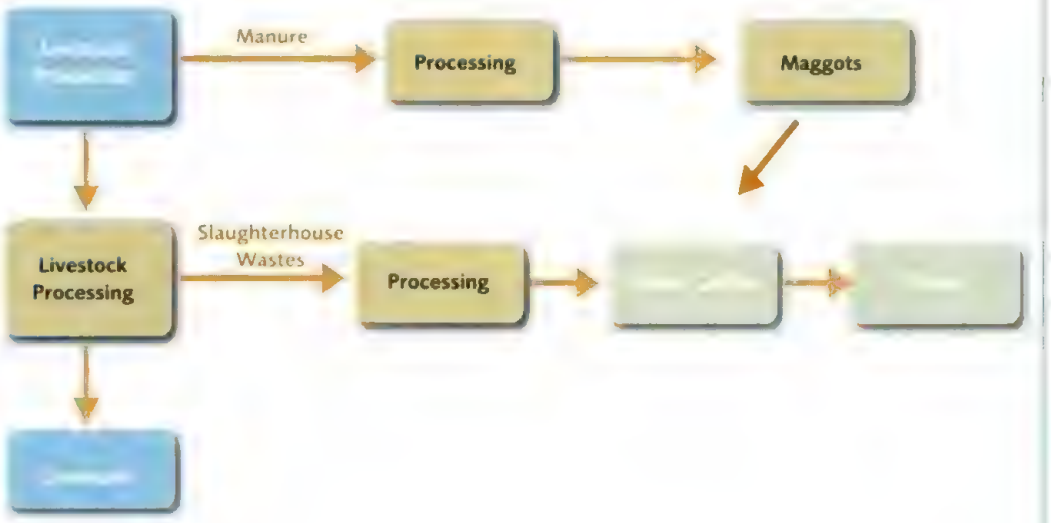
The most important environmental impacts of processing livestock result from the discharge of waste-water (de Haan *et al.*, 1997). This area is least developed with respect to integration with fish culture. A major problem in developing countries is the tendency for processing plants to be located in peri-urban areas where infrastructure and markets are best developed but land and water are limiting

Other major differences between modern and traditional agro-industry are the facilities and scale of operation. There are large differences in the type and quantities of by-products produced that depend on the type of livestock and processing waste (Box 3.G)

Regulation of the size and distribution of processing operations can encourage the recycling of processing wastes through

Figure 10

Comparison of possible strategies for using livestock production and processing wastes in aquaculture



Source: Little and Edwards (1999)

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BOX 3.G

By-products from livestock and processing waste

- The biological oxygen demand (BOD) of wastewater from red meat slaughterhouses may be over 25 kg BOD. tonne live weight^{-1}, of which 10 kg is from blood, compared to less than 10 kg BOD. tonne live weight^{-1} for poultry.
- Tanneries typically produce around 100 kg BOD tonne raw hide^{-1}
- Dairies produce less than 5 kg BOD tonne of milk processed^{-1}
- Markets also affect the value of the processed livestock. For example, whereas offal may be highly prized and preferentially consumed in some markets, in others it is a disposable waste

Source: de Haan *et al.* (1997)

aquaculture. In Thailand, as road and other infrastructure have improved, chicken processing plants are moving away from flood-prone rice growing areas in provinces near Bangkok to the centres of broiler production within maize growing, upland areas. Hybrid catfish farms which utilize much of their wastes, are similarly relocating to these areas (Ingthamjitr, 1997).

A major constraint to the use of most tannery waste is the use of chromium in the tanning process. Chromium is particularly toxic to fish and other aquatic organisms. It is a major problem in the Calcutta wastewater-fed fisheries, causing seasonal mortalities and undocumented risks to humans from consumption of such fish

Adding value to livestock wastes through simple on-farm processing has now developed where conditions are suitable: typically in the vicinity of larger towns and cities; and usually by entrepreneurs well connected with urban markets. In one study, livestock processing wastes in Pathum Thani, Thailand were more commonly used by farmers with diversified farming systems (livestock, fish, vegetables, orchard), than rice farmers adopting fish production (Edwards *et al.*, 1983). Location of aquaculture within peri-urban zones also makes the use of other agro-industrial by-products possible. These include waste

BOX 3.H

Green blowfly larvae used to process pig manure to fish feed

Limited land and/or water availability may preclude conventional integrated waste-fed aquaculture. The production of a live feed, such as the green blowfly larvae, *Lucilia sericata*, on pig manure and its use as a substitute for a pelleted feed for intensively raised African catfish (*Clarias gariepinus*) in cages placed in ponds stocked with Nile tilapia (*Oreochromis niloticus*) was demonstrated.

Key outcomes were

- Catfish production of 6 tonnes year^{-1} based on the manure from a standing herd of 1000 fattening pigs was demonstrated
- The static water pond in which the catfish cages were suspended ensured that environmental impact of both pig and catfish systems was minimal
- Integration of tilapia with catfish improved nitrogen retention by over 30 percent
- Manure after maggot production still retained more than half the original nitrogen content but its reduced moisture content increased its value as a horticultural input
- Catfish fed maggots alone over an eight week culture period grew to market size (100g)
- Catfish fed maggots alone fed had slightly lower survival (75-80 percent) than pellet-fed fish(>84 percent), possibly due to their voracious feeding that led to physical damage

Source Nuov (1993), Nuov *et al* (1995)

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TOP LEFT
Maggot production based on pig manure. Green blowfly (*Lucilia sericata*) larvae are raised in batches over 4-5 days and fed to African catfish

TOP RIGHT
Maggots being produced in manure placed next to fish ponds can be pushed into the water to feed the fish

LEFT
Feeding broiler chicken intestines to *Pangasius* catfish

human food from canteens and restaurants and food processing wastes. In Thailand and some other parts of Asia, noodle processing waste, stale noodles and bread products, and soybean, brewery and distillery wastes are commonly used. Many of these products are also used for feeding livestock, particularly pigs (Figure 11).

Live-feed organisms

The use of livestock manures as substrates for live-feed organisms such as insect larvae or crustaceans for feeding high-value fish also has potential where land costs prohibit semi-intensive aquaculture. Live feeds can be used as complete diets or to supplement pelleted feeds for fish species such as hybrid *Clarias* catfish raised in intensive systems (Box 3.H). Such low-tech solutions not only produce fish but also increase the value of the original waste, principally by reducing smell and moisture level

Slaughter house wastes

Commercial examples of poultry slaughter house wastes being used as feed after simple processing for carnivorous fish such as *Clarias* catfish and snakehead exist in Asia (Box 3.I). The rapid deterioration of viscera and other slaughterhouse wastes restricts their use to areas close to the source. In Thailand such wastes are

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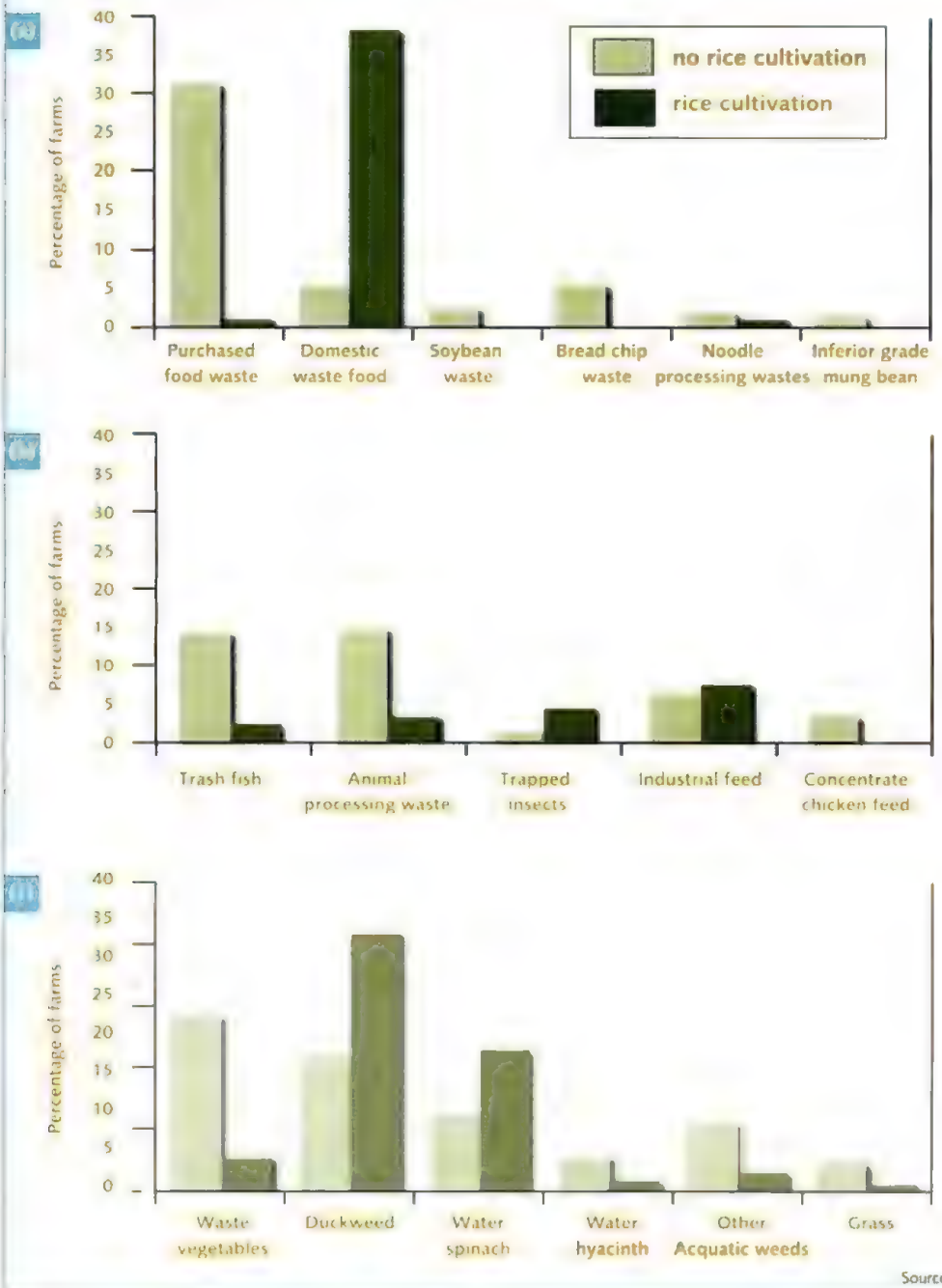
Figure 11

Percentage of farms in Central Thailand using various fertilizer and supplementary feed inputs for fish culture (a) waste food from human consumption and agro-industry (b) animal by-products and animal feed (c) vegetable matter.



Source AIT (1983)

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BOX 3.1

Chicken slaughter house waste fed to catfish

Poultry slaughter house wastes are in great demand for feeding hybrid *Clarias* catfish (*C. macrocephalus x C. gariepinus*) in Thailand. The practice has evolved on the back of a booming industry and export of boneless chicken meat in which broilers are processed in-country producing large amounts of by-products. Heads, viscera and thighbones, that constitute about 10 percent of the liveweight of the broiler are the main by-products fed fresh after simple on-farm grinding and mixing with a binder.

Food conversion ratios of 4-5 (wet:wet basis) are attained under farm conditions in which yields of the air-breathing hybrid catfish may exceed 100 tonnes. ha^{-1}. Competition to purchase slaughterhouse by-products has resulted in segmentation of the recycling business with wholesalers contracting waste, to further remove meat scraps for human consumption before use of residual waste for catfish feed.

Effluents from the fish culture systems are minor as water exchange is minimal and increasingly is pumped into neighbouring ponds in which polycultures of herbivorous fish are raised in fertilized, semi-intensive systems.

Source: Little *et al.* (1994)

usually refrigerated on-farm and may be traded. The advantages of an export industry that both stimulate employment producing value-added products and produces food for sale locally are clear (Box 3.J).

After processing of broiler chickens in Thailand about 10 percent of the liveweight is used for feeding hybrid *Clarias* catfish.

BOX 3.1

Feeding maize to catfish

1st order benefits

- Local maize and soybean production stimulates broiler production
- Broiler production waste used to raise herbivorous fish
- Local labour used for de-boning chicken
- Chicken slaughter wastes used to raise catfish

2nd order benefits

- Expertise in feed manufacture stimulates development of value-added feed ingredients and knowledge
- Benefits to crop farmers (stable markets)
- Benefits for peri-urban skilled and unskilled employment
- Low-cost chicken and fish products for sale benefit local consumers
- Reduction in polluting effluents

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4 Environmental Aspects

The interaction of livestock and fish, either as specialized or integrated activities, and the environment can be considered in two ways (1) how the environment impacts on opportunities for livestock and fish production and (2) how livestock and fish production impact on the environment. Impacts can be positive or negative in both directions (Figure 12); in this section we explain how integration tends to enhance positive and minimize negative impacts.

Clearly both fish and livestock production are strongly influenced by, and affect, their agro-ecology. Aquaculture, by nature of the aquatic environment, is often integral to, and difficult to separate from, surrounding natural and human habitats such as rivers, lakes, reservoirs and coastal areas. Aquaculture has closer proximity to 'wild' organisms than animal husbandry that may threaten (through disease transfer, parasitism or predation) or support (through supply of seed or feed) aquaculture (Edwards, 1997). The key reliance on water leads to an enhanced vulnerability to pollutants and contaminants moving with water in and out of aquaculture systems because of the fluid medium.

Impacts on the environment of livestock considered alone, aquaculture alone or both together have both a **local** and **global** significance. There are two major interrelated problems facing developing countries and their relationship with the wider world. Sustaining poor peoples' livelihoods directly, and indirectly, through enhanced agricultural productivity and, at the same time, ensuring that local and global environments are safeguarded. How nutrients are used, and recycled, in food production is of major importance to meeting these challenges. Water, and how food production affects its availability for other uses, is of major significance, not only to the sustainability of local communities but also to broader geopolitical stability. Irrigation systems that promise increases in arable crop yields and cultured fish production, typically undermine important riverine and flood-plain fisheries that may be

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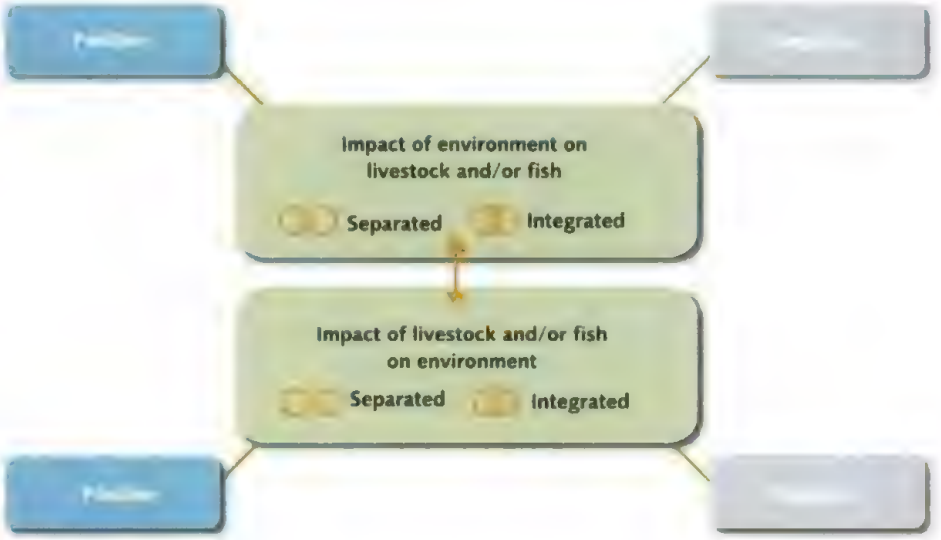
The two-way interaction between aquaculture and the environment involves numerous factors which range from positive to negative in their impact.



Source Modified from FAO (1997a)

fundamental to the food security needs of the poor. The integration of livestock and fish production may contribute to stabilising nutrient and water use, allowing increasing demands to be satisfied

More resource-intensive, livestock and fish farming will have increasingly negative impacts on the global environment. These include the effects on global warming to which they directly and indirectly contribute. Fossil fuel use that is the major underlying cause of greenhouse gas production, supports much of the current food grain and concentrate production that underpins the culture of livestock and carnivorous fish species. The impact of increasing demand for concentrate feed on arable systems and the world's natural stocks of fish to support growth in intensive livestock and fish production could be reduced if integrated farming became more widespread

Local development of productive integrated systems can also contribute positively to the maintenance of biodiversity. There are two important aspects; reducing impacts on natural resources and adding value to local strains and varieties. Maintaining the genetic diversity of both wild and cultured animals and plants is critical for longer-term sustainability of both small-holder and large-scale commercial food production

4.1 Nutrients

Intensive recycling of nutrients was critical to support dense rural populations, such as traditionally occurred in much of Eastern Asia (King, 1911). Urbanization and industrialization of agriculture have led to de-linking of nutrient recycling and production to produce food, or in the words of Borgstrom (1973): 'the breach in the flow of mineral nutrients'. The flow of nutrients

entering urban centres as food via processing and distribution systems has become unidirectional - a development that has been accelerated by sewerage systems that channel human wastes away from densely populated city centres (Vallentyne, 1974). Alternative fertilizers, firstly guano and later industrially manufactured fertilizers, began to free farmers from dependence on local nutrient recycling.

A serious geographical imbalance in nutrient distribution now exists; large amounts of nutrients are imported into industrial regions that then spend large amounts of money to avoid eutrophication. In contrast developing areas, which sometimes are the original source of the nutrients, are becoming nutrient-depleted. Cropping cassava on fragile tropical soils for export as low-cost livestock feed ingredients for developed countries is both unsustainable on a local scale and, through deforestation and erosion, has much broader adverse environmental impacts. Intense exploitation of fish stocks to produce fish meal has major implications for the integrity of marine ecosystems. The international trade in commodities has driven many of these practices, but many poorer peoples' livelihoods are now dependent on them.

Aquatic systems have been used for nutrient disposal, both intentional and accidental since the beginnings of human settlement. Removal of the mainly organic wastes of people settled around waterways and waterbodies was convenient and, initially, left few traces. As the nutrient load increases however, water quality deteriorates with a number of obvious effects. The silting up and nutrient enrichment of community reservoirs and dams causes as many problems to communities around them as the disposal of sewage in industrialized countries. Shallow community water bodies commonly become choked with unmanaged macrophyte vegetation or waterways become plankton-rich and, if organic loads are unchecked, hyper-eutrophic and eventually anaerobic. Both types of plants can be the basis for nutrient recovery if used within managed systems and examples exist of both traditional and modern systems. Aquatic macrophytes can remove nutrients and have been important components in integrated farms in China and Northern Viet Nam to feed both pigs and herbivorous fish. Plankton-based aquaculture is the basis of semi-intensive production of filter feeding fish.

4.1.1 NUTRIENT RECYCLING IN AGROECOSYSTEMS

Agroecosystems differ from natural, unmanaged ecosystems in their larger and more rapid turnover of nutrients. Such systems producing food or fibre are therefore more open for nutrient transport across boundaries (Frissel, 1977; Tivy, 1987). Moreover, the level of nutrient inputs used can define the intensity of farming. Modeling of nutrient cycling is well established for conventional agriculture (Figure 13) but analysis of agroecosystems involving crops, livestock and fish is recent. Understanding how a pond stocked with fish affects fluxes of nutrients through the farm can be critical to developing more efficient and less polluting agriculture, animal husbandry and aquaculture.

Extensive agriculture, such as unimproved pastoral systems, relies on the natural or little modified soil nutrient reservoir, and has low yields of biomass and nutrients (<20 kg N ha^{-1}) In contrast, specialized intensive agriculture requires large nutrient imports but shows high productivity. Nitrogen outputs of intensive grass production can exceed 400 kg N ha^{-1} (Frissel, 1977). Feedlot livestock can greatly exceed these values because high-density livestock are fed concentrates

Mixed farming is generally intermediate between these two extremes, receiving low to moderate inputs from outside. The close relationship between wastes from livestock used for fertilization of crops and use of N-fixing plants both reduce the need for N imports, and improve nutrient efficiency. Farming systems in which long-lived organisms such as perennial crops and large livestock are important components are more like self-sustaining natural cycles with increased system biomass and reduced primary productivity/biomass ratios (Dalsgaard *et al.*, 1995)

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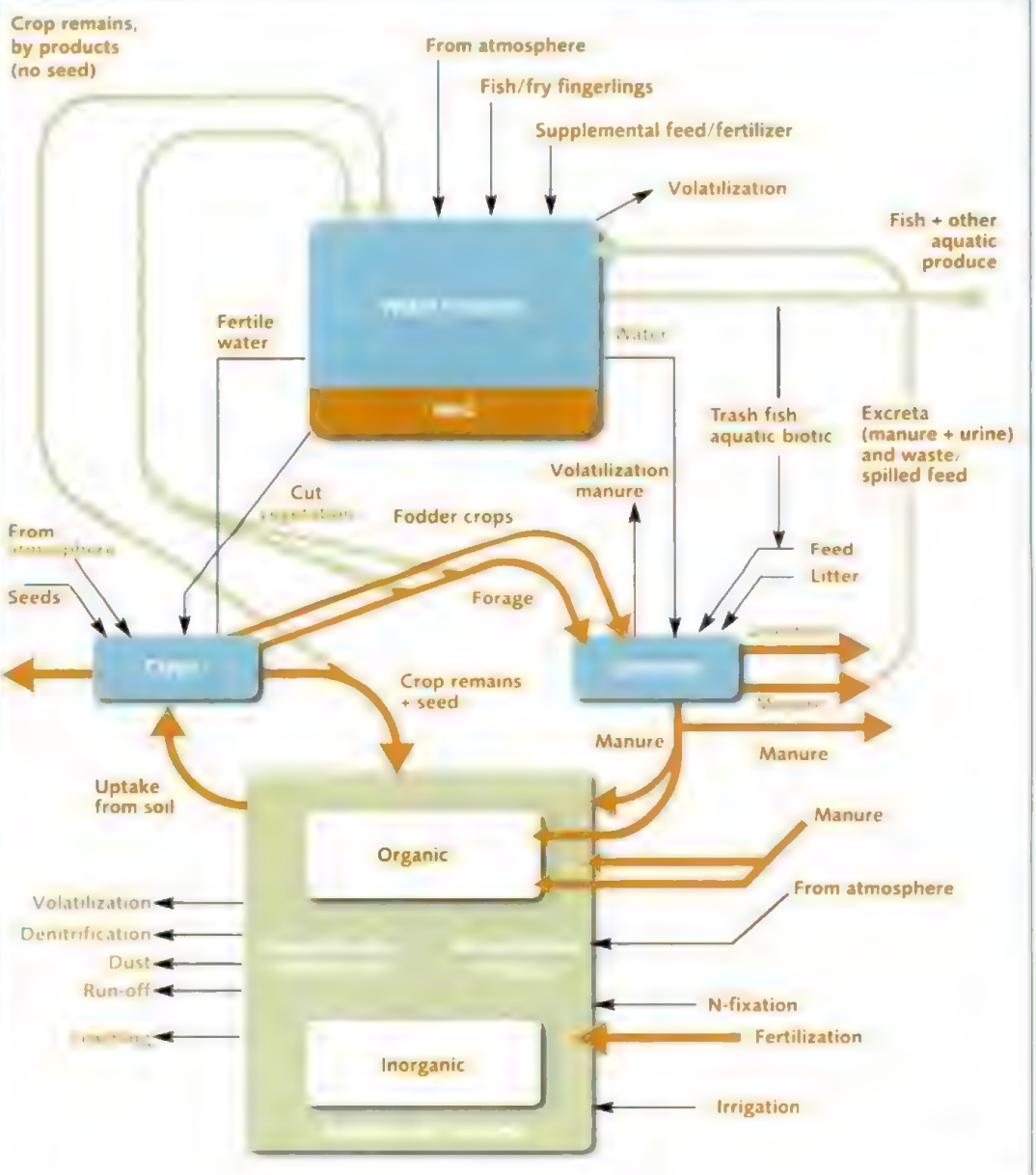
FIGURE 13

Nutrient cycles for an agroecosystem involving crops, fish and livestock. The crops, livestock and soil pathways, for which the major linkages are brown arrows, are reproduced unmodified from Tivy (1987). The fishpond, its major linkages with crops and livestock (dark green arrows), other inputs and outputs have been added here. Nutrient recycling within and between the fishpond water and mud are omitted for clarity. In some traditional Asian systems, human (household) excreta is an important additional input to crops and fishponds and kitchen waste the livestock and fishponds.



Source: Edwards (1993)

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BOX 4.A

Nutrient flows among village subsystems and between village and outside systems in Nguyen Xa village, Viet Nam.

In an analysis of nutrient flows in and through a village in the Red River Delta in Northern Viet Nam, the majority of nutrients left as rice grain and food products processed from rice i.e. noodles, wine and pigs. A substantial surplus of nutrients was also found to be leaving the fields in drainage water, polluting the water source into which it flows. Most crops and crop residues were consumed in the village, fed to livestock, used for making manure/compost or burned for fuel. Chemical fertilizers were the major source of nutrient inflow to the village system (Figure 14).

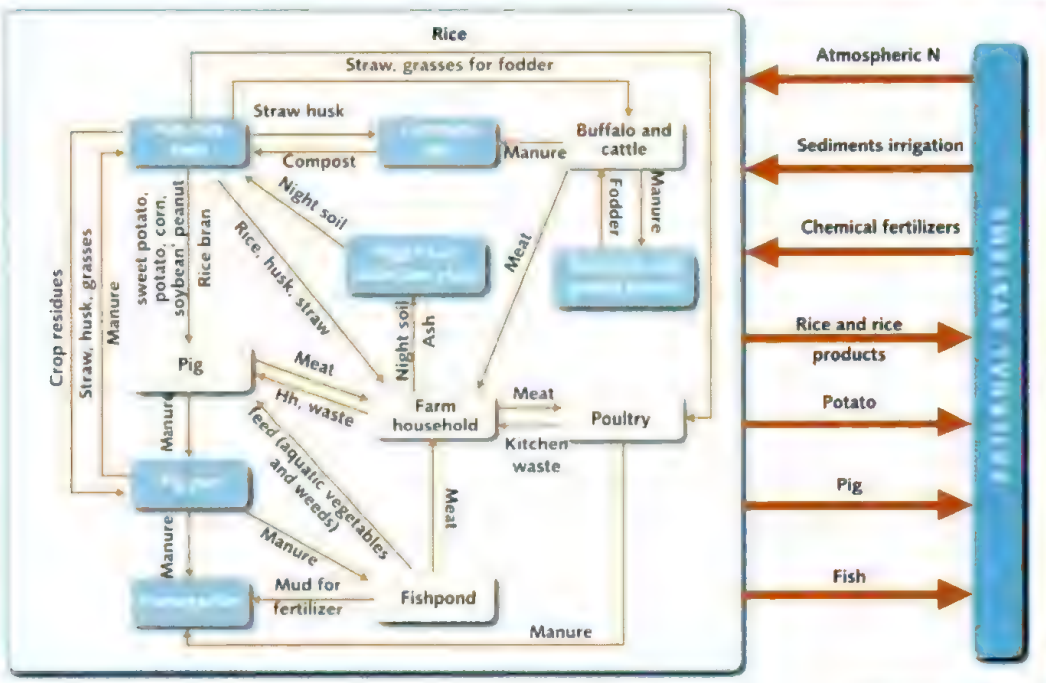
Source: Le and Rambo (1993)

However, even a simplistic analysis of nutrient fluxes can indicate that mixed or integrated farming systems can be far from a closed ecological cycle. Imports of pig and human food into the seemingly tightly managed agroecosystems in Southern China were required to support the large nutrient exports of commodities such as silk, fish and sugar (Edwards, 1993) and a similar situation exists in Northern Viet Nam (Box 4.A).

A key factor in estimating overall system efficiency is not only the harvestable yield from a given level of input, but the practicality and yield from organisms raised on recycled nutrients in the waste. The relative 'leakiness' of nutrients from agroecosystems, as run-off and leaching and percolation into subsoil, and ultimately aquifers is also relevant. Decomposition of livestock manures spread on field crops and leaching of nutrients is a major environmental problem, even in developing countries where nutrients are

FIGURE 14

Nutrient flows among village subsystems and between village and outside systems.



Source: Le and Rambo (1993)

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limiting (see Box 4.B). Intensive specialized livestock production tends to lead to a greater waste of nutrients. In the Netherlands, 52 percent of pig manure, 60 percent of manure of fattening calves and 80 percent of chicken manure is wasted (Harrison, 1992).

4.1.2 NUTRIENT EFFICIENCY IN LIVESTOCK

Relative efficiencies of livestock

The role of livestock in supporting human populations, and their relative efficiency in terms of using land and food resources, are highly specific to the human and agro-ecology of the region. Whereas monogastrics (pigs and poultry) may compete for cereals, pulses and concentrates suitable for direct human consumption, ruminants may utilize plant production unsuitable for direct human food Livestock can have important roles in improving total efficiency of conversion through use of by-products unsuitable for, or wastes from, direct human consumption. Spedding (1984) observed how monogastric and ruminant feed development could be synergistic. Extraction of energy/protein-dense food from herbage crops for pigs and poultry, leaving residues with value for ruminants, is one option. A good example of this is the use of sugar cane juice in pig feeds in Viet Nam (Preston, 1990). Another strategy is the biological processing of fibrous wastes in which earthworms or dipterous larvae are used to concentrate high-quality, microbial protein from decomposing animal and vegetable waste

Any comparison of livestock in terms of nutrient efficiency is problematic. Protein conversion values, or protein to energy ratios have been used but any meaningful comparison is difficult because different animals can use different quality feeds. Thus, although poultry yield most protein per unit of gross energy fed compared to a range of other animals, the feeds used contain a higher proportion of metabolisable energy (ME), usually in the form of more expensive feeds. Efficiency expressed as protein conversion or protein per unit of energy consumed (g protein/MJ of ME) of single animals indicates that eggs, milk, milk plus beef, poultry and pig production are high and breeding animals low. But any animal production requires breeding animals and thus consideration of nutrient efficiency has to be made on the basis of populations rather than single animals. A high reproductive rate and low turnover of breeding animals improves overall efficiency. Highly productive pigs and poultry have low overhead feed costs for breeding animals compared to larger animals. Selection for earlier age at first breeding, reduced length of and improved regularity of a breeding cycle, greater fecundity and improved early survival of the young, all theoretically improve reproductive efficiency. In practice they may be counteractive or incur such high support costs as to be impractical. It is also known that separation of males and females and use of different diets and management can enhance feed utilization, but may not be practical.

Approaches to improve efficiency

Different approaches are known to improve overall efficiency of nutrient use in ruminants and monogastrics. Replacement of traditional sources of protein with non-protein N is one approach useful for ruminants. Use of micro nutrient blocks for animals consuming poor-quality diets, and use of by-pass protein can all increase the efficiency of protein use. Development of diets with improved amino acid balance and optimal relationships between micro-nutrients has improved the nutrient efficiency of monogastrics.

Modern livestock systems can produce relatively less waste but it is often more nutrient-rich than from traditional systems. Certain practices influence the amounts of N and P (Box 4.B)

AQUACULTURE

A comparison of intensive and semi-intensive aquaculture reveals that conversion efficiencies are greater for fish fed formulated diets (21-53 percent for N, 11-28 percent P) than fish raised in ponds receiving livestock manure or inorganic fertilizer (5-25 percent and 5-11 percent respectively) (Edwards, 1993). However, these

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BOX 4.8

Approaches to reducing livestock waste and environmental pollution

- **Supply nutrients to the required level. This can be accomplished by better knowledge of nutrient availability (N, P) in the feed, a better knowledge of the animals requirement and a better agreement of supply and requirement.**
- **Enhance digestibility of P and protein. Use of microbial phytase to improve digestibility of P reduces needs for supplementation; enzyme treatment of non-starch polysaccharides; reduce anti-nutritional factors through treatment of ingredients and processing of complete diets.**
- **Change feedstuff composition. For example selection of highly digestible sources of P (mono-calcium phosphate rather than di-calcium); use of amino acid supplementation and reduction in protein levels.**
- **Improve feed efficiency.**

Other environmental effects:

- **Levels of potassium supply exceed demand by a factor of 3-5 and levels in fresh water can exceed accepted levels by a factor of 2-4.**
- **High moisture level of livestock waste increases transport costs for disposal.**
- **Although feed additives may reduce excretion of N and P as a result of better feed conversion, copper and zinc growth promotants can accumulate in soils.**
- **Free-ranging pigs requiring more fibre in the diet have lower feed conversion and more waste per unit of meat produced.**
- **Specific pathogen-free herds can improve feed conversion by 10-15 percent.**

Source: Modified from Jongbloed and Lenis (1995)

differences reflect a fertilized system in which phytoplankton is produced; and are far from a 90 percent decline in efficiency expected from an extra step in the food chain. The values reflect the high degree of nutrient recycling that occurs in food webs in fertilized ponds and, particularly in polycultures, how efficiently they are exploited

Developments in intensive salmonid production are towards 'low pollution' diets in which highly refined processing of food ingredients produces more highly digestible, low P diets. These have resulted in declines in measured P effluents, despite rising production. However this has been achieved largely through use of greater amounts of fishmeal, with associated environmental impacts. Additionally, the level of soluble, excreted nutrients. (kg fish produced^{-1}) have probably increased with the use of such diets.

4.1.4 NUTRIENT RELATIONSHIPS IN LIVESTOCK–FISH SYSTEMS

Integration of livestock and fish production can improve the overall efficiency of nutrient use in the system and reduce the level of effluents. Relative inefficiencies in nutrient use by livestock can be compensated for by recycling in fish production. Efficiency of nutrient recovery declines as input levels increase, a clear case of diminishing marginal returns (Table 4.1). There are also differences in efficiency of nutrient transfer between wastes collected from different livestock systems. Both fish yield and N recovery were considerably poorer for ruminants fed poor-quality diets than feedlot ducks fed complete feeds. Such information is useful for estimation of opportunity costs of livestock–fish systems (Chapter 7).

Wastes are often composed of fractions of different value to fish culture. The mixing of feed with manure for example can improve its value and nutrient recovery of the overall waste. Ad libitum feeding of ducks resulted in an estimated 10 percent of the feed being wasted and directly available to the fish in the case above. In ducks, species, sex and type of feed were all found to significantly affect feeding efficiency and the amount of waste feed 'lost' to direct consumption by fish in integrated systems (Naing, 1990)

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TABLE 4.1

Efficiency of N recovery in livestock-waste fertilized earthen ponds (200 m) stocked with Nile tilapia.

Livestock			Nitrogen	
Number of adult buffalos. ha^{-1} pond	Number of egg-laying ducks. ha^{-1} pond	Extrapolated fish yield (tonnes ha^{-1} yr^{-1})	g to produce 1 kg fish	Conversion efficiency (percent)
	500	4 8	119	22
	1000	8 0	143	18
	1500	10.1	169	15
50		1.9	226	11
100		2 6	331	8
150		3 1	417	6

Source AIT (1986)

Significance of livestock and fish production in the global environment

Livestock and fish production impact on the wider environment in a variety of ways. The resources used to feed, maintain, process and distribute livestock and fish products are considerable. However, intensified production of both livestock and fish must occur if natural habitats are to be preserved (de Haan *et al.*, 1997)

Intensification of livestock based on known technologies adapted to local situations could reduce impacts on the remaining natural environment (Murgueitio, 1990). While intensive livestock production is a major source of pollution, degradation of range lands and soil erosion in developing countries is associated with increased numbers of ruminants that are often extensively managed and of low productivity (Steinfeld *et al.*, 1997). Extensively managed ruminants have been identified as a major factor in both tropical deforestation and increase in greenhouse gases. These claims are particularly important given the growth in livestock production, which at 4.5 percent year^{-1}, is higher than for agricultural production as a whole.

4.2.1 GLOBAL WARMING

Agriculture has been implicated as a major cause of global warming that is leading to adverse changes in the world's environment. These include rising sea-levels that are likely to particularly affect densely populated flood-plains in Asia, communities that are also most dependent on cultured freshwater fish. This dependence is set to increase substantially, and the poorest are most at risk (Harrison, 1992)

Carbon dioxide, nitrous oxide and methane are the main greenhouse gases linked directly and indirectly to livestock production. Permanent carbon release is mainly related to use of fossil fuels and deforestation, for which intensive animal husbandry and extensive ruminant production respectively are important. Nitrous oxides are associated with production and use of N-fertilized pasture and arable crop-based feeding

Livestock and manure management contribute about 16 percent of total annual production of methane (de Haan *et al.*, 1997) and unproductive ruminants contribute especially to emissions (Leng, 1991). A larger fraction of feed is

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BOX 4.C

Summary of nutrients and the environment

- **Aquatic systems have often been used for disposal of waste nutrients, leading to water quality deterioration**
- **Agricultural systems are characterized by greater nutrient fluxes than natural systems**
- **Sediments in aquatic systems can act as sinks for nutrients, aiding in their conservation and use**
- **Leakiness occurs in all agro-ecosystems, especially the intensive, but integrated systems tend to recycle a greater proportion of nutrients in the system**
- **Assessment of the use of nutrients by livestock needs to consider population efficiency and the value of the feed converted**
- **The feed industry approach to improved efficiency is based on refining performance through formulations that meet the animals needs more exactly**
- **Conventional feed efficiency of intensive aquaculture is high and progress has been made towards less polluting diets**
- **Semi-intensive aquaculture has high system efficiency**
- **Integration of livestock and fish can compensate for poor feeding efficiency in the livestock alone**

used for maintenance in low productivity animals, resulting in a higher level of methane produced per unit of product. Also, lower quality feeds with poorer digestibility have higher emissions per unit of feed intake. Intensifying livestock production could therefore have impacts on both global warming and livestock productivity. More than 80 percent of methane from livestock arises from digestive fermentation and the balance is linked to manure management. Manure handled dry produces little methane, but feedlots, which produce large amounts of liquid manure, are the main contributors. Pigs and poultry cannot digest fibrous feeds and have relatively low fermentation emissions; the rapid increase in the numbers of these monogastrics compared to grazing animals on a world-wide basis is one reason for the stagnant methane emissions from livestock, despite growing numbers (de Haan *et al.*, 1997). Improved productivity is also believed to contribute to stability of methane emissions related to digestion.

The recycling of methane after controlled collection and digestion is attractive, particularly for large pig and dairy operations with high energy requirements but has been less attractive for small-holders. Lower cost systems based on low-cost polyethylene tubing have also been promoted in the Mekong Delta, Viet Nam (Herrera, 1996). Farmers raising fish, however, prefer to use fresh pig manure directly and biogas slurry is rarely used to fertilize ponds (Bui, 1996). The disposal, with or without intermediate fermentation in a biodigester, of feedlot livestock wastes in aerobic fishponds would reduce methane and CO_2 emissions considerably.

Expansion of fertilized aquatic systems stocked with grazing fish has greater capacity for sequestering carbon dioxide than even well-managed terrestrial pasture, as aquatic productivity may be most limited by carbon in otherwise fertile systems. Flooded rice fields of Asia have been identified as another major source of methane. The stocking of rice fields with fish that graze the soil-water boundary in ricefields ensures that it remains aerobic, with methane production correspondingly reduced.

Water is a renewable resource but its availability, if considered as the amount per person per year, is limited. Increasing water scarcity is undermining food security and becoming the cause of local and international conflicts (Falkenmark, 1999). Whereas water consumption of livestock is related mainly to the amounts required to produce their feed or fodder (Pimentel *et al.*, 1997), the water used for holding fish during production needs to be considered in

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aquaculture (Beveridge and Phillips, 1993). Levels of seepage, evaporation and recycling of water in fish culture systems are therefore important criteria, as is the value of water after its use for fish production

Water use efficiencies of livestock are dependent on both the type of feed given and the efficiencies of conversion. Intensively fattened beef dependent on irrigated crops is therefore water hungry. In contrast, poultry as efficient converters of diets mainly consisting of rain-fed cereals (sorghum, maize and wheat), can be produced using much less water.

The integration of livestock and fish production can reduce the amount of water used per unit of animal protein, compared to separate, stand alone production of poultry and fish in ponds (Table 4.2). This is basically because the amount of water required to produce feed for fish is eliminated. In more intensive systems, however, water can be used more efficiently if the fish are fed and raised at higher densities, and water is filtered and recycled.

A direct comparison of the efficiency of water use in different livestock and aquaculture systems is not realistic in other ways. The construction and siting of fishponds in watersheds to collect and store water that otherwise would be unavailable contributes to increasing the amount of available water for the whole farming system i.e. fish, livestock and crop components. The capital costs for any single component might be too high whereas the integrated use of the water 'spares' this initial cost, and reduces risk (Chapter 9). Moreover integrating livestock waste with semi-intensive fish production may increase the 'value' of the water since its nutrient level, and hence value for irrigation, will be increased when used locally in agriculture (Little and Muir, 1987; Pullin and Prein, 1994).

The potential and constraints to the integration of livestock and fish are reviewed by system in Table 4.3. Open ponds within diverse farming systems offer most potential for significant interaction. Water shortages have been an important motivation for closer spatial integration between livestock, fish and crop production in parts of Asia (Box 4.D).

BOX 4.D

A need for water encourages integrated fish culture

- **In Northeast Thailand, ricefield-pond systems became foci for intensified integrated farming but water availability for dry-season vegetables for home consumption was the primary motivation. Less poultry disease in flocks raised in the system and perennial water for raising fish were secondary motivations (Surintaraseree and Little, 1998).**
- **On-farm reservoirs in Central Luzon, Philippines, have allowed farmers to both plant a dry season rice crop and earn an additional 20 percent net income from fish, but in drier areas competition between water use for rice and fish in irrigation systems occurred (Fujisaka, 1993).**

Intensive fish production, especially in cages and raceways, tends to be highly consumptive of water (Table 4.2), degrading the value of large amounts of water required by other consumers. Regulators in the industrialized world view intensive aquaculture as a polluter of multipurpose water resources and tend to limit its size and distribution. Eutrophic water enriched by wastes from intensive aquaculture or livestock production requires extra treatment costs prior to distribution and use

The case has been made for intensification of livestock production to safeguard remaining areas of wildlife habitat and, indirectly, biodiversity (de Haan *et al.*, 1997). The expansion of fish culture, closely integrated with this intensified livestock production may also reap specific benefits in terms of protection of aquatic habitats. Exploitation of wild fish stocks has contributed towards collapse or impoverishment of native fauna but this is often based on industrial fishing to produce fish meal for feeding

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TABLE 4.2

Water consumption of fish production integrated with livestock or as a stand-alone enterprise

System	Water consumption (m^3 t^{-1})			Source
	Feed related	Environment[a] related	Total	
Beef [b]			100 000	Pimentel *et al.* (1997); feedlot fattened
Broiler chicken [b]			3 500	Pimentel *et al.* (1997)
Tilapia polycultures integrated with broiler chicken		6 060	6 060	Hopkins and Cruz (1982); Philippines
Tilapia monoculture:				
• Intensive earthen ponds	<3 500	8 000	<11 500	Mires and Anjouni (1997); Israel
• 'Dekel' system	<3 500	460	<3 960	Mires and Anjouni (1997); Israel
• Tanks	<3 500	50 000 60 000	>50 000	Beveridge and Phillips (1993); Kenya

[a]seepage, evaporation; [b]livestock alone

TABLE 4.3

Potentials and constraints to integration of livestock with fish by system

System	Potential for livestock waste providing significant nutrients to fish production	Fish densities/level of intensification	Predisposing conditions	Environmental impacts
Open ponds	High, proven concept	Low-medium	Waste recycling tradition, low fish: feed cost ratio; well developed livestock industry	Minimal, possibility of seepage to ground water
Ponds/tanks with recirculation	Low	Medium-high	Water shortage; high fish:feed cost ratio	Minimal, design and management density dependent
Cages	Some	Medium-very high	High cost of land/water for pond aquaculture; availability of reservoirs/ lakes; moderate to high fish:feed cost ratio	Potentially very high
Raceways	None	High-very high	Low cost; high quality water source; high fish: feed cost ratio	High, little possibility of nutrient removal because low concentration/high volume

intensively raised livestock and fish. Low-cost farmed fish can reduce these pressures, and the accompanying environmental degradation, by providing the market with alternative supplies, perhaps to a point where natural stocks can recover although this is probably unrealistic due to growing population pressure and different players catching and culturing fish.

The drainage or conversion of wetlands for aquaculture is a common strategy that risks losses to both biodiversity and the livelihoods of the poor (Chapter 7). Culture systems that

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depend on modification, rather than wholesale change of natural habitats and use indigenous species need greater attention in this respect

The use of indigenous fish in culture may result in conservation of endangered species There has been relatively little development of polycultures based on indigenous fish but experience in Java, where combinations of several indigenous carps and gouramis are traditionally cultured, suggests this is a promising strategy Moreover, most fish eating cultures that have relied on natural stocks are familiar with consuming fish of a variety of species and size. One constraint is that many highly valued indigenous species are carnivorous and not good primary culture candidates. They may be useful, however, as components of semi-intensive systems that add value to polycultures mainly comprised of low value herbivorous fish Stocking a variety of indigenous, carnivorous fish along with snakeskin gourami (*Trichogaster pectoralis*) is now a well-developed system in Thailand. The need for more diversity was market-driven and favoured use of indigenous and exotic species raised together to suit local needs (Yoonpundh, 1977). Production was enhanced using livestock manures and the system has emerged as an alternative strategy to high-risk intensification based on monoculture. It also allows resource-poor farmers to raise species with which they are familiar, and which are of high value.

Combinations of wildlife and livestock are now recognized for their value in increasing biodiversity and incomes for the people dependent on them such as pastoralists and ranchers (Steinfeld *et al.*, 1997). The survival of wild aquatic species and their habitats, may also be more assured if they can be utilized within extensive and semi-intensive culture systems.

Integrated fish culture protects biodiversity in more indirect ways. Increased demand for feed concentrates creates significant pressures on the environment and aquatic habitats in particular through high rates of water extraction and the deterioration in quality that often occurs. Large quantities of both surface and ground water are used to irrigate cereal and oil crops that comprise most concentrates, and contamination of water run-off and drainage with agrochemicals typically occurs. When concentrates are used in semi-intensive systems, more fish can be produced per unit feed than intensive systems in which natural food is unimportant.

Integration of livestock and fish is highly efficient if the fish species raised are herbivorous or omnivorous. The production of carnivorous fish has implications for equitable use of resources (see Chapter 7) since the small trash fish required to either feed them directly (as in certain catfish and snakehead systems in Southeast Asia) or indirectly for fishmeal production can be eaten directly by the poor

Intensive aquaculture of carnivorous species uses a rapidly increasing proportion of the limited global supply of fishmeal as fish inputs are two to four times the volume of fish outputs in the production of farmed salmon and shrimp (Naylor *et al.*, 1998) Although the amount of fishmeal used in livestock diets has declined recently, particularly for grower and finishing feeds of monogastrics, livestock remains the major user at about 75 percent of global production

Cultured fish may be used increasingly to supply fresh fish and fishmeal needs. Production costs for waste-fed herbivorous fish are now similar to the price paid by manufacturers of valued added products such as pet foods for quality trash fish. Market pressures may also stimulate the emergence and acceptability of waste-fed fish for these purposes as consumers are becoming increasingly aware of environmental issues

The use of small quantities of cultured fish to balance carbohydrate-rich on-farm diets for livestock has been suggested (Chapter 9).

4.2.3 IMPACTS OF LIVESTOCK

Water pollution caused by residues and purposeful disposal of chemicals used in

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BOX 4.8

Summary of factors through which livestock and fish interact with the global environment

- Both intensification and extensification of livestock production threaten the global environment; intensive aquaculture is also often environmentally unfriendly
- Increases in deforestation and greenhouse gases, and a deterioration in water quality, are direct or indirect affects of more livestock
- Improved productivity of livestock and rice production, and integration with fish culture, can reduce methane emissions
- Semi-intensive fish culture can improve efficiency of water use on-farm directly through the role of ponds and dams in the harvest, conservation and storage of rain and run-off water
- Water consumption in aquaculture is related to both production of feed and the culture environment. Semi-intensive systems have high feed-related efficiencies but more environment-related losses compared to some intensive systems
- Biodiversity can be negatively or positively affected by livestock–fish integration depending on its location relative to, and dependence on, natural water resources. The species used (exotic/indigenous) and type of culture system practiced will also affect biodiversity
- Integration of livestock and fish can reduce the pressure on feed resources and the habitats which support them, through reductions in, or contributions to, fishmeal supplies
- Drugs and other chemical used in livestock production can act directly or indirectly on aquatic systems, reducing opportunities for integration with aquaculture. Cultured fish in surface water act as bio-indicators of the health of the aquatic environment

livestock production is typically highly harmful to fish and other aquatic organisms. Poor fish growth and survival in a system based on goat wastes from animals dosed prophylatically with anti-helminths has been reported in experimental systems (Mohsinuzzaman, 1992). Water pollution from agrochemicals to control livestock disease vectors such as ticks and tetse fly can negatively affect fish if inappropriate drainage or discharge is used

In temperate climates, attention has been drawn to the negative impacts of grazing animals on riparian systems around which they are often concentrated, through their consumption of vegetation cover and resulting run-off. Increased nitrate and phosphate levels affect plant communities, silt deposition and flow dynamics of surface waters. Aquaculture integrated within the farming system, especially of less tolerant species, can act as a bio-indicator of environmental health.

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5

Design criteria for livestock manured ponds

Practical designs of semi-intensive aquaculture systems integrated with livestock are based on a range of factors. An understanding of the dynamics of aquatic ecosystems is required to appreciate the mechanisms by which fish grow in ponds receiving livestock wastes, and the constraints to their production. Maintaining productivity of natural food growing in the fertilized pond and an environment conducive to fish survival and growth have to be considered. The principles of fertilization, well-established in terrestrial agriculture, have only recently been adequately researched but the three dimensional aquatic environment offers a range of options still to be thoroughly explored.

Intensification of fertilized systems through use of supplementary feeds is a well-known strategy in animal husbandry but, again, is unrefined for aquatic systems.

The characteristics of livestock wastes themselves are also frequently unreported and unremarked but are critical to the design and management of integrated systems. How wastes are used in fish culture systems also affects efficiency and productivity of the system as explored below.

5.1 Manured pond dynamics

Schaeperclaus (1933) first noted that static water ponds act as both 'the stall and the pasture' for fish capable of exploiting the web of natural feed stimulated by fertilization. In contrast to terrestrial systems managed for herbivores,

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maintaining a balance between feeding and living environments is both more complex and critical. Whilst the concept of carrying capacity in terms of number, or biomass, of fish or livestock that can grow per unit area is similar, the necessity to maintain adequate water quality, especially dissolved oxygen, is critical in aquatic systems.

Ponds with optimal water quality but little food will be unproductive. Equally, food-rich ponds will under-perform or risk complete loss if levels of the different feed organisms and fish, are excessive and use up dissolved oxygen (DO). Both sanitary engineers and aquaculture scientists have quantified how wastes stimulate the productivity of ponds through nutrient enrichment and how water quality changes rapidly as a result. The diurnal cycle of DO that occurs in unfertilized systems becomes extreme as loading of nutrients increases. These swings are mainly caused by photosynthetic production and respiratory uptake of DO by dense blooms of phytoplankton that develop after nutrient loading. Clearly, the key aspects of nutrient management are to ensure that DO, and natural food levels remain adequate and in balance throughout fish growth.

Many factors can affect the management of waste-fed ponds, which may have their origin at macro-, local as well as micro- or pond level. Climatic and cultural factors can affect the potential for integration of livestock and fish production at macro-level (Table 5.1). National policies such as those relating to fertilizer and

TABLE 5.1

Factors affecting use of animal wastes in ponds

	Primary factors	Secondary factors	Ameliorating factors
Macro-level	• Climate	• Temperature • Water availability	• Seasonal production • Irrigation
	• Cultural	• Tradition/aversion to use of wastes of fresh wastes	• Processing, treatment • Education
	• Availability of nutrients e.g. concentrate feeds, inorganic fertilizers		• Policy • Infrastructure
Local level	• Site • Soils • Exposure • Access for nutrients, seed, management • Competition for nutrients • Quality of nutrients	• Rainfall and water supply • Creation of turbidity. • Acidity • Adsorption of nutrients into sediments • Exposure to wind • Sunshine, duration and intensity	
Pond level	• Pond design • Frequency of waste addition • Combination of size and species of fish • Harvest strategy		• Avoid deep (>3m) or shallow (<0.6m) water • Polyculture and mixed size stocking and harvesting may optimize nutrient efficiency

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feed manufacture and import, can affect availability and cost of nutrients at local level, supporting or undermining attempts to intensify livestock and fish culture.

Local resource levels are also affected by both physical e.g. soils, topography, water availability, and social and economic factors that can foster or constrain the development of integrated practices. At the pond or plot level, design and management of fish culture and associated animal husbandry have to balance resource constraints and opportunities.

Stable and high water temperatures and sunlight ensure year-round growth of both fish and their natural feeds. The tropics, in which average monthly water temperatures remain above 18°C, are ideal for culturing fish using livestock waste as inputs, although it is also practiced in sub-tropical and temperate climates during warmer periods of the year.

Manures can be used fresh, or after processing, to enhance natural food production in sun-lit ponds as much of the nutrient content of feed given to livestock is voided as excretory and faecal waste. Although some nutrition may be derived directly from the waste, high-protein natural feed produced on the nutrients released from the wastes mainly in the form of plankton is more important. Fish feeding low in the food web, e.g. carps and tilapias, benefit most from this type of management since they can utilize plankton, benthic and detrital food organisms effectively.

The nutrients contained in organic wastes stimulate a range of natural food organisms that may be suspended in the water column, attached to substrates, or within the sediments. Sediment-water interfaces are key feeding niches for some fish species. The availability and value of phytoplankton and bacteria, the dominant organisms in most waste fed ponds, are linked to specialized feeding habits of the fish. A variety of carps and tilapias can grow rapidly on such natural feeds alone, employing strategies similar to grazing (filter feeding) and browsing (ingestion of attached periphyton). A detritus-feeding niche, in which a large amount of sediment is ingested, may also be important. Most fish are opportunistically inclined to consume macro-invertebrates of various types, molluscs, insects, polychaete and oligochaete worms and crustaceans.

Several factors affect the level of waste loading and standing stock of fish that can be supported. The species of fish raised is important both from a perspective of varying feeding niche and sensitivity to water quality, especially DO in static water ponds without mechanical aeration. Carps are limited to standing stocks of <3 tonnes ha^{-1} whereas tilapias may be harvested at standing stocks of over 5 tonnes ha^{-1}. Pond design, depth, shape and position also contribute to maintaining water quality since these factors affect exposure to wind, sunlight and run-off from adjacent land.

The 'carrying capacity' of the fish pond, or maximum biomass of fish that can raised in a pond of given feed and water quality, can be enhanced by increasing fish density and using feed to supplement natural food. Supplementary feeds are generally relatively high in energy and low in protein to balance protein-rich natural food.

Water quality, particularly the level of early morning DO, limits the amount of wastes that can be used. Under tropical conditions, input levels in excess of 100 kg dry matter (DM) ha^{-1} d^{-1} often 'overload' the system over a typical fish culture cycle (4-8 months), causing early morning deficits of DO (Figure 15). Balancing the production of wastes and the requirement of the fishpond is a key aspect of management (Colman and Edwards, 1987; Knud Hansen, 1998). An understanding of the livestock densities required to provide optimal loadings of nutrients for given areas of fish ponds is key to the design of manure-fed systems.

The quality of livestock wastes used in fish culture varies greatly. The direct feeding value of manure is poor because of low levels of metabolisable energy and digestible protein (Wohlfarth and Schroeder, 1979). Any spilled livestock feed mixed with the manure will increase direct feed value. Nutrient composition is a useful guide to the value of the waste as a fertilizer, especially levels of total N and P; levels of nutrient density as expressed as a ratio of these major nutrients with C (C:N:P) is also a

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BOX 5.A

Benefits of animal manures in pond culture

Manure:

- **Is a good source of N, P and C, the latter may be limiting in rain-fed or other ponds with low alkalinities**
- **Can provide a substrate for zooplankton production**
- **Can assist in clarification of clay turbidity in pond water**
- **Can reduce the rate of P adsorption into pond sediments if present as a layer at the sediment-water interface**
- **Can reduce seepage of pond water**
- **Can act as direct feed, especially for detritivorous fish**

Source: Modified after Knud Hansen (1998)

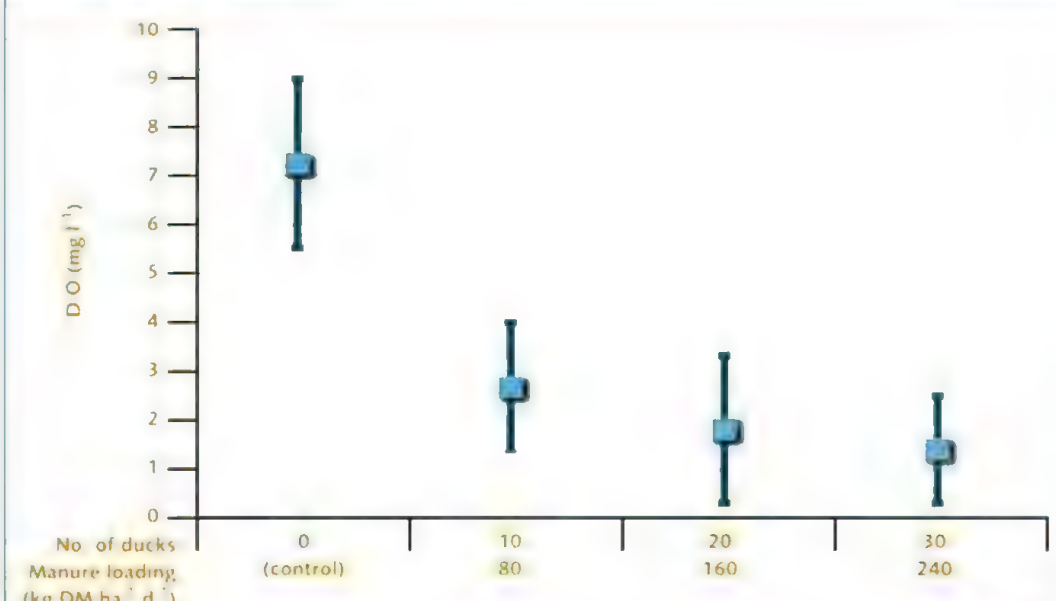
good indicator. However, these data may tell little about the availability or release of nutrients that can be taken up by the phytoplankton. The rate of release of soluble N and P is useful for predicting manure quality. A range of other benefits from use of animal manures in fish production have also been identified (Box 5.A)

FERTILIZATION

High fish production in fertilized ponds is mainly attributed to stimulation of autotrophic production, that is the growth of phytoplankton that filter-feeding fish can use directly as feed and which form a major proportion of the detritus in the pond. Phytoplankton is also the main source of DO in the pond. Both living and detrital phytoplankton are protein-rich and are the basis of the food web that can support the growth of a range of herbivorous and omnivorous fish. Technical and economic considerations determine how fish ponds are best fertilized and managed.

FIGURE 15

Mean dissolved oxygen (DO) in mg l^{-1} at dawn for ponds (200 m^2) receiving different levels of manure loading. Error bars show standard deviations.



Source: AIT (1986)

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Nutrients

Fertilization aims to supply the optimal level of nutrients to stimulate phytoplankton production. Practically these nutrients are limited to N, P and C; other nutrients are required only in trace amounts and supplied by the fertilizer, supplementary feeding and the natural environment. Analysis of the nutrient content of healthy phytoplankton indicates the level of requirement which is at a ratio of approximately 50:10:1(C:N:P). The N:P ratio can vary from <1.5:1 in N deficient algae to >15:1 in P-deficient algae. Carbon is often ignored but is required in the greatest amounts. Waste-fed ponds are seldom C limited because bacterial breakdown produces carbon dioxide but inorganically fertilized ponds with low alkalinity often require lime to ensure sufficient C. Molluscs can also drastically reduce C levels through removal of carbonate for shell growth.

Selecting fertilizers and fertilization rates to meet the nutritional needs of phytoplakton or algae has a history of confusion that recent research has clarified. Earlier studies, often using low densities of fish or stocking non-filter feeding fish, failed to show a clear relationship between N and yields. Much of this research was based on temperate lakes in which N fixation was important in supporting the relatively low fish productivity. It is now known that in warmwater freshwater ponds, N is usually the most limiting nutrient and that high levels are required to optimize yields of phytophagous fish such as Nile tilapia. Available P can also easily limit algal productivity as it is rapidly fixed by various cations (Fe^{2+}, Ca^{2+}, Mg^{2+} and Al^{2+}), and bound up in the sediments. Sediments with high clay content or containing acid-sulphate soils are particularly 'greedy' Fertilizer management should consider previous P inputs or 'pond history'; ponds used for a prolonged period and receiving nutrient inputs will require relatively less fertilizer

This summary is based on the work of: Goldman (1979); Colman and Edwards (1987); Knud-Hansen (1998). Shrestha and Lin (1996); Knud-Hansen *et al.* (1991).

Fixed rates

The use of fixed fertilization rates as guides to farmers is based on experimentation at relatively limited sites and cannot be simply extrapolated to ponds everywhere. Moreover, most research has focused on a single phytophagous fish, the Nile tilapia. A range of factors, including livestock and waste management systems considered below, may affect fertilization response. Differences in response by individual ponds even located only a few metres apart indicate that fixed rates should be used only as a guide to avoid over or under-fertilization. Farmers can use general guidelines, if presented in an appropriate way, and adapt them to meet their individual requirements. Indeed, farmers in China and India learned to manage fertilized fishponds before the principles were elucidated by scientists. Clear explanations of how nutrients work in the pond ecosystem are particularly valuable, as opposed to 'recipes'

There is generally concern among extension staff that excessive fertilizer levels, particularly of N fertilizers, can result in fish mortalities. Generally this is more of a danger if fixed rates are extended. A typical scenario is the effect of such overloading during periods of low temperature or low light conditions when the capacity of the pond ecosystem to absorb and utilize them is lower than normal. When conditions return to normal nutrients can then be present in surplus quantities causing dangerous levels (see Box 5.B) or unstable phytoplankton blooms that can 'crash' causing sudden declines in DO and elevated levels of ammonia

Animal wastes with unbalanced nutrient levels, typically high C:N ratios and N:P ratios well below optimal, are often compensated for by increasing manuring rate. This can lead to reduced DO levels and fish growth (Box 5.C)

Detritus and periphyton

The availability and usefulness of very small micro-algae (nannoplankton; diameter < 10 µm) that tend to dominate waste-fed ponds and the diets of filter-feeding fish has been the subject of much research. Mechanisms that describe their ingestion e.g. Northcott and Beveridge (1988), digestion (Moriarty, 1987) and avoidance of toxins which they sometimes contain (Beveridge *et al.*, 1993) have been given.

The relative contributions of autotrophic and

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BOX 5.8

Fixed fertilization rates defined by experimentation

N and P loadings of 4 kg. $ha^{-1}d^{-1}$ and 2 kg. ha^{-1} d^{-1}, respectively, were defined as optimal for tilapia monocultures in a series of experiment using both organic and inorganic fertilizers at the Asian Institute of Technology and other research stations[1].

Harvested yields of 4-5 tonnes. ha^{-1} of 200-250g fish in around 6 months are possible if 1 fish. m^{-2} is stocked. Higher stocking densities (up to 5 fish. m^{-2}) can increase net fish yields further. If smaller fish are acceptable and multiple stocking and harvest is practiced, net extrapolated yields of 12 tonnes. ha^{-1} $year^{-1}$ are possible.

Inorganic N fertilization in excess of these levels resulted in :

- total ammonia concentrations in pond water (>1.5 mg/l), which at the typically high daytime pH levels (>9) lead to high levels of toxic, unionized ammonia concentrations.
- possible effects of groundwater nitrate levels.

Optimal levels of N fertilization are already about five times greater on an annual area basis than the maximum national average in Asia for land-based agriculture.

P fertilization needs may be lower than recommended if the sites where the P is adsorbed in pond sediments are filled. This may occur through:

- previous heavy fertilization with P-containing inputs;
- livestock manures with a relatively low N:P ratio;
- use of ricebran, containing high levels of P as a supplementary feed.

[1] The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) supported by USAID have undertaken research in Honduras, Rwanda and the Philippines andThailand.

heterotrophic pathways to the productivity of fertilized fish ponds were once contested (Schroeder, 1977; Colman and Edwards, 1987) Most now conclude that algal-derived detritus, whether suspended, attached or settled is usually the dominant and most nutritionally valuable form of detritus available, even in waste-fed ponds. It supports a huge range of zooplankton, substrate dwelling micro-invertebrates and fish directly. Non-filter feeding fish can still derive adequate nutrition in waste-fed ponds by exploiting these feeding niches but the density at which their growth can be supported, the carrying capacity, is correspondingly lower than for filter feeding species.

Fish that can graze 'aufwuchs', or attached periphyton, are less well supported in conventional fertilized ponds as substrate is limited. Recent studies indicate that increased substrate availability can improve fish yields, especially if the substrate in enriched with nutrients by soaking in manures. Periphyton-based aquaculture may be of particular benefit when size/scale of culture unit, or cost of nutrients preclude conventional fertilization. Significant constraints include the availability and cost of substrate in rural areas where biomass is heavily exploited for fuel and other uses

Frequency of fertilization

Fertilization, especially if fertilizers require transport to the pond, can be laborious and often result in infrequent application of bulky animal wastes. In contrast, strategic livestock management and system design can result in substantial reductions of both costs for livestock waste removal and fertilization of fish ponds (5.2.3). Integrated systems, in which wastes continuously enter the fish pond and 'feed' the algae probably result in optimal algae productivity since nutrient depletion is least likely to occur

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BOX 5.C

High loadings of ruminant manure

Ruminant manures from grazing buffalo had a C:N ratio of 26 and a N and P contents of 1.4 percent and 0.2 percent DM, respectively.
To achieve a loading of 4 kg N $ha^{-1}d^{-1}$, 300 kg DM. ha^{-1} d^{-1} of manure had to be loaded.

Dissolved oxygen quickly declined to deleterious levels through a combination of:

- **bacterial decomposition of the dry matter;**
- **release of tannins from the manures occurred at high levels leading to;**
- **inhibited phytoplankton growth (<15mg/l).**

Source: Edwards *et al.* (1994), Shevgoor *et al.* (1994)

(Knud Hansen, 1998). More occasional, heavier loadings are more likely to 'shock' the pond system, leading to explosive bacterial and algal growth and low early morning DO.

If fertilization adheres to fixed schedules, unbalanced nutrient levels may occur that do not meet the needs of dynamic and unpredictable alga populations; algae in fish ponds are prone to species change or succession that impact on nutritional and water quality . During periods of continuous rainfall, when static water ponds may overflow, the demand for nutrients may be higher and more frequent than dry periods for example. Thermal stratification also occurs, especially in deeper ponds that result in elevated nutrients levels (Szyper and Lin, 1990). After breakdown during heavy rain or wind, nutrients that have accumulated in the lower levels of the water and sediments are released, exceeding the pond's capacity.

5.3 PRINCIPLES OF SUPPLEMENTARY FEEDING

Supplementary feeding has been a rather neglected part of aquaculture science, perhaps due to the intensive nature of most 'modern' developed country aquaculture and its reliance on carnivorous fish species. However, the intensification of traditional aquaculture in Asia is encouraging the use of supplements (Yakupitiyage, 1993; De Silva, 1993).

Supplementary feeding of a fertilized pond can both increase the fish yield and reduce the time to harvest but understanding how supplements work compared to complete feeds is critical. The provision of supplementary feed is required if fish of large individual size are required. Thus, although Nile tilapia of between 200-250g can be produced on fertilizer alone within 5 months, individual growth thereafter is slow as natural feed alone does not meet optimal growth requirements (Edwards *et al.*, 2000).

Supplements are generally used commercially if the use of complete feeds is uneconomic. Both scientists and farmers are attempting to optimize technical and economic performance by developing feeding strategies. These require knowledge of local resource and market opportunities.

Supplementary feed may also be required when conventional fertilization cannot be optimized, if sufficient manure is unavailable, its use is unacceptable or high turbidity reduces phytoplankton productivity. Periods of heavy rainfall can make 'green' pond conditions impossible to maintain

How supplementary feeds work

Farmers providing supplementary feed to any stock, animals or fish, have a fundamentally different aim to giving a 'complete' feed. An intensively raised animal, for example a hen or salmon raised in a cage, has negligible access to natural feed of any type and must be given a nutritionally balanced ration. In contrast, pasture-raised cattle or herbivorous fish require a feed that can complement the low-cost terrestrial or aquatic, pasture respectively, most economically. When herbivorous fish eat only natural feed, part of the protein is used for energy, which could be 'spared' by giving supplementary feed high in energy. Furthermore, if natural feed is in short supply, especially as the density of filter-feeding fish increases, energy becomes limiting before protein. This explains why energy-rich grains and brans are commonly used in fertilized ponds and why, if fed alone or in ponds with little natural feed, they are nutritionally unbalanced and result

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in poor growth. Extending this concept of 'limiting nutrients' by developing supplementary feeds that will support growth in static-water systems at higher fish densities has become of great commercial significance (Edwards, 1999).

Timing of supplementary feed

The low value of many freshwater pond fish may make supplementary feeding throughout the production cycle unattractive. Use of formulated feeds is still relatively uncommon unless the fish are relatively high value carnivorous species or destined for local luxury or export markets in developing countries, even if they are available. Strategic feeding of low-cost supplements is most cost effective at the beginning and end of the fish culture cycle

Fish seed are a valued-added product for which economic, complete feeds have been unavailable but for which supplementary feeding is now the norm. Juvenile production of most freshwater species, in which hatchlings are raised to finger-sized fish ready to stock into on-growing ponds to produce table-size fish is normally undertaken in zooplankton-rich, earthen ponds. Even species that are herbivorous later in life require a diet high in crude protein and supplementary feeding, especially if high quality ingredients are used, allows much higher densities of fingerlings to be 'nursed' to marketable size. High survival and quick turnover of stocks is essential for most nursery operations and supplementary feeding tends to improve returns compared to fertilization alone.

The fattening of table fish is a strategic option much employed in livestock production but little researched in fish culture. Conceptually the method may have application for a range of fish species, but especially those that can 'graze' until the size when feeding becomes economic. Fattening will often be most cost effective in cages; the origins of cage culture were probably the fattening of undersized and less valuable, wild fish before marketing. Feeding high quality pellets as a supplementary ration in tilapia monocultures has been found to be most cost-effective if limited to fish that have attained 100-150 g after 3 months pond culture based on fertilization alone (Diana *et al.*, 1996)

Feeding levels

Feeding of readily available by-products such as ricebran in fertilized ponds can be cost effective, but even cheap feeds can reduce returns compared to fertilization alone if optimal levels are exceeded. Rice bran boosted yields of a Nile tilapia monoculture receiving egg-laying duck manure by between 10-150 percent (AIT, 1986), but its use may not be cost effective. The 'law of diminishing returns' was demonstrated when a low feeding rate (1 percent body weight day^{-1}) increased yields, profitably by between 28 and 40 percent, for two levels of duck manure loading, but doubling feeding rate (2 percent) increased yields by a mere 4 percent or reduced them by 16 percent respectively (Yakupitiyage *et al.*, 1991). This situation demonstrates that overall dry matter inputs into ponds must be carefully controlled in waste plus supplementary-fed systems or poor water quality can undermine yield improvements through improved nutrition. Feeding levels of grown tilapia (100-150g) can be reduced to 50 percent of satiation without a decline in individual growth (Diana *et al.*, 1994)

Non-filter feeding fish

Carp farmers optimize the productivity of polycultures in India by strategic use of home-mixed, supplementary feeds in ponds receiving both poultry manure and inorganic fertilizers. Fish are stocked as stunted seed, trained to feed from plastic fertilizer bags with holes at the base Optimal profitability has been achieved by doubling rates of fertilization over official recommendations (Nandeesha, 1993). The relative scarcity of benthic organisms make the energy sparing effect of supplementary feeds particularly valuable for benthic-feeding carps (Yakupitiyage, 1993); this may explain why the effect of supplementary feed is less pronounced for filter feeders in phytoplankton-rich water

Supplements to complement natural food

Supplementary feed should complement limitations in the natural food present in the system. Critical standing crop (CSC) identifies the biomass of fish at which growth is retarded due to poor nutrition (Hepher, 1988). Tacon and

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De Silva (1997) have incorporated the standing crop of fish and natural food into the concept (Figure 16). Edwards *et al.* (2000) propose that supplementary feeding be classified into four stages. Research on Nile tilapia clearly indicated that only vitamins and minerals (excluding P) did not affect performance as indicated by growth and body composition (Box 5.D).

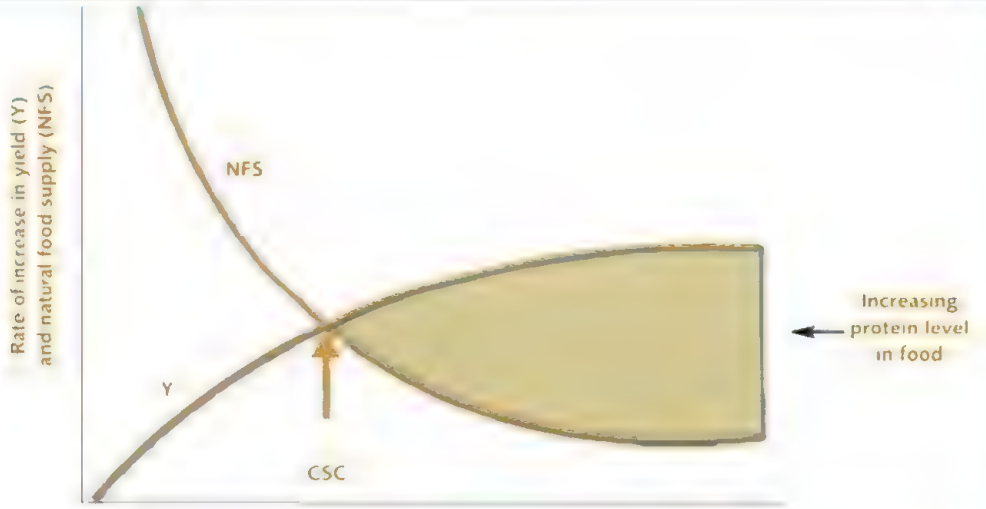
Supplementary feed under conditions of lack of natural feed

Farmers with turbid water ponds that do not respond to fertilization typically have poor results with supplementary feed alone. The problem is particularly common during the rainy season in ponds with unstable dikes. Fertilizers may also be washed out as ponds overflow under such conditions. Yields from ponds fertilized daily with inorganics alone at optimal levels (4 kg N and 2 kg P ha^{-1} day^{-1}) were compared with using the equivalent amount of cash to purchase pelleted feed, rice bran or cassava chips. Pelleted feeds gave the best result but the researchers recommended farmers to use equal costed amounts of inorganic fertilizers and commercial pelleted feeds under such conditions (Edwards *et al.*, 2000).

Waste characteristics

Manures contain considerable amounts of valuable nutrients for recycling through aquatic food webs to produce fish. Both the total amount and the proportion of nutrients available can be highly variable. Between 72-79 percent of the N, 61-87 percent of the P and 82-92 percent of the potassium in the diet was present in the waste of feedlot, egg-laying hens (Taiganides, 1978) indicating the scale of the resource. Generally the wastes from monogastric animals (pigs and poultry) are more nutrient-dense than wastes from grazing ruminants but the range of ruminant waste quality varies enormously (Table 5.2). Solid manure will often be mixed with a variety of other fractions such as urine, bedding, washing water and waste feed

Schematic depiction of changes in the natural food organisms and fish yields, in relation to standing crop of the cultured organism and the ensuing protein needs of the supplemental feed (s)



Source: Tacon and De Silva (1997)

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BOX 5.D

Categories of supplementary feeding

Stage	Category	Limited natural feed	Enhanced natural feed	Notes
1	No supplementary feed		X	Water may also be turbid
2	Energy-rich feed		XX	e.g. rice bran (*dry, wet mash*)
3	Energy-rich feed + some building blocks	X	XXX	e.g. soybean cake and noodle-waste (*wet dough, pellet*)
4	Energy-rich feed + some building blocks + catalysers	XX	XXX	Di-calcium phosphate (DCP), salt (*often pelleted*)
5	Complete feed	XXX	XXX	Balanced amino and fatty acids, vitamins, minerals, and attractants (*pelleted*)

X - XXX; least to most important

BOX 5.E

Disappointing results with supplementary feeding

- Green *et al.* (1994) found no benefits to yields in poultry-manure fertilized ponds that also received high-quality pelleted feed. This can be explained by the growth of the fish being supported by natural feed alone at the low densities used (2 fish. m^{-2}).
- Yields may also be constrained by other factors such as seasonally low temperature and DO levels. The relatively low yields (1.5-4.7 tonnes.ha^{-1} $year^{-1}$), reported in Hong Kong by Sin (1980) despite supplementary feeding of carp polycultures fertilized with duck manure, appear to be related to such water quality factors. Green *et al.* (1994) also reported poorer yields in supplementary-fed, poultry waste-fertilized ponds during cooler periods.
- Since supplementary feeding works by complementing natural feed, if there is little natural feed, supplements are ineffective. Such can be the case in clear, plankton-poor environments such as occur when farmers close to water supplies allow constant exchange of water or when high levels of silt turbidity reduces transparency, and productivity of plankton.

Species, size and sex also affect the quantity of animal manure produced Husbandry level and waste management techniques can also greatly affect waste collection and use in fish culture Complete collection of wastes may be impractical or costly, particularly for livestock raised under extensive or semi-confined conditions. Sometimes wastes cannot be used immediately, necessitating processing and/or storage and this will also affect their nutrient content. The quantity of waste produced by any animal is related to body weight, and thus any growth during a production cycle affects the design of livestock-fish systems. The availability of soluble nutrients from wastes of different types also affects their value, and is often related to age and original quality of the manure Any calculation of the number of livestock required to optimise a given area of fishpond therefore needs to consider a wide range of variables

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BOX 5.F

Summary of key factors affecting manured pond dynamics

- Natural food produced through fertilization alone can support cost-effective production of herbivorous and omnivorous fish
- The production of natural feed and maintenance of water quality need to be balanced in fertilized ponds
- Phytoplankton are usually the most important source of natural food and DO
- Plankton-derived detritus can be an important source of food for fish; lack of substrate limits the importance of periphyton in conventional systems
- The ratio of major nutrients in organic wastes (C, N, P) characterizes their quality and value for fish culture
- Fixed fertilization rates can be used as a guide to required levels but optimal strategies require adjustment for local and seasonal variation
- In general 'little and often' reduce risk of 'overloading' the pond and enhances efficiency of nutrient use
- Supplementary feeds can improve the viability of fertilized systems under many conditions
- High levels of natural feeds, temperature and other physical factors remaining within the normal range, and appropriate densities of suitable fish species stocked are key criteria

5.2.2 SPECIES, SIZE AND SEX

Livestock waste output is often described in terms of nutrients available. unit body weight ^{1} (g nutrient.animal unit^{-1} day^{-1}). This can vary greatly within the same species or strain managed under different conditions but for monogastrics raised on formulated diets under intensive conditions is relatively predictable Relative waste production (g. kg live wt.$^{-1}$) declines with age and size and food requirement also change. Thus more, smaller animals will generally produce more and higher quality waste than the same biomass of larger animals of the same type Breeding animals fed high quality but restricted rations tend to produce smaller quantities of nutrient-rich manure than animals being fattened ab libitum. Monogastrics fed complete formulated diets have nutrient-rich wastes whereas ruminants fed fibre-rich feed produce wastes relatively high in dry matter, but poor in N and P. The large individual size of most ruminants means that outputs of total N and P per animal can be substantial. Low nutrient density and presence of tannins negatively affect the value of ruminant faecal wastes in aquaculture, reducing its value as pond fertilizers compared to that suggested in actual levels of N and P. However, intensification through confinement and improved feeding can improve the availability and quality of wastes

The diverse nutritional needs of egg-laying and meat breeds of poultry also greatly affect manure composition. The calcium and P-rich excreta of laying birds reflect diets designed to support egg-shell development and the high fibre content in waste of juvenile (replacement) laying birds fed reflects the content of fibre in their diet. The considerable proportion of total N found in urine and washing water (Figure 17), as opposed to solids has important implications for their management. Generally urine contains little P, except for pigs.

5.2.3 FEED AND WASTE MANAGEMENT

Feedlot, scavenging and intermediate systems

Livestock managed outside of feedlots have more variable waste characteristics and generally less of the nutrients produced can be collected. Animals that are stalled some or all of the time, and fed cut-and-carried forages and/or

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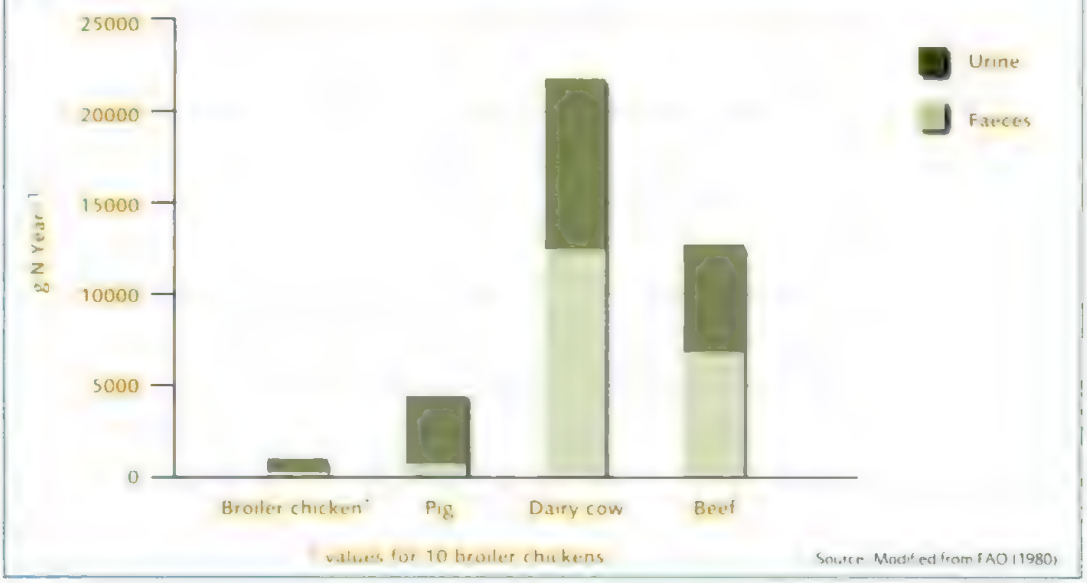
TABLE 5.2

Input and output of poultry waste fed-aquaculture

System	Inputs (g m^{-2} day^{-1}) Poultry waste DM	N	P	Other DM	N	P	Output (g fish m^{-2} day^{-1}) Fish		
Feedlot									
Egg-laying ducks	6 71		0 07				Tilapia		200 m² ponds, 6 months (Edwards *et al.*, 1983)
Broiler chickens	10 0	0 4	0 46		-		Tilapia, Common carp	2 87	400 m² ponds, 3 months (Hopkins and Cruz, 1982)
Layer chicken	14 3	0 4	0 3				Tilapia	1 33	1 000 m² ponds, 5 months (Green *et al.*, 1994)
Layer chicken	1 07	0 03	0 018	-	0.47	0 23	Tilapia	2 75	220 m² ponds, 5 months (Knud-Hansen *et al.*, 1991)
Scavenging									
Muscovy duck	9 7	15	0.10		-	-	Tilapia	1 38	5 m² tanks, 3 months , ducks fed
Egg-laying duck	3 0	0 23	0.03		0.17	-	Tilapia	1.21	200 m² ponds, 4 months
Egg-laying duck	1 24	0 20	0 01		0.17	-	Tilapia	0 53	200 m² ponds, 4 months (AASP, 1996); paddy rice

Source: ... and Satapornvanit (1996)

Annual production of nitrogen in faeces and urine for various livestock



Source: Modified from FAO (1980)

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BOX 5.G

Goat management level affects nutrients collectable for aquaculture

- **A range of goat management options was compared with respect to system output characterized by goat performance and nutrient collection. Zero-grazed *Katjang* meat goats fed grasses, tree legume leaf and ricebran were managed alongside animals tethered for day-time grazing and receiving a concentrate (ricebran) or cut legume supplement during night-time confinement. These options were compared to goats that were also tethered but had no supplementary feed. The supplementary use of leguminous leaves particularly improved the collectable N in wastes, almost to the level of zero-grazed animals. Liquid wastes (urine plus washing water) contain about half of the N produced and this could be used to totally replace inorganic N in fish production. Using ricebran as a supplementary feed enhanced P levels in the waste.**
- **The importance of frequent waste collection was also compared in tethered animals with no supplementary feeding. The frequency of waste removal affects both the amount of collectable nutrients and animal productivity. Goats stalled overnight on infrequently replaced bedding show reduced productivity *and* the amount of nutrients collected, particularly N, are reduced substantially compared to daily cleaning and waste collection (Figure 18).**

Source: Little and Edwards (1999)

concentrates, tend to show both increased productivity and produce wastes of higher quality and collectability (Box 5.G).

Feed quality

Quality of feed greatly affects both livestock performance and waste quality for aquaculture However, there are few data for fish yields derived from pig production other than from complete balanced diets. An exception is Long (1995) who found that although fattening hybrid pigs fed only cooked village ricebran and chopped water hyacinth grew at half the rate of pigs fed balanced rations, their waste could still support extrapolated fish yields (more than 4 tonnes ha^{-1} $year^{-1}$) higher than the norm in the Mekong Delta

Performance and waste availability of semi-feedlot poultry have also been little studied but preliminary research is encouraging. In scavenging poultry, manure quality is greatly affected by the quality and quantity of supplementary feeds, which in turn affects fish production. Compared to confined birds fed complete diets, nutrients in the waste are low, resulting in poorer performance of fish raised on the waste (Box 5.H; Table 5.2). However, using more waste from a larger flock of ducks can compensate for the smaller amount of lower quality manure produced per duck from scavenging birds penned for supplementary feeding and waste collection only at night.

There are tradeoffs between benefits to livestock and fish regarding the type of supplementary livestock feed used. Egg-laying ducks (Khaki Campbell x local hybrids) fed paddy grain at night produced poorer quality manure than those fed rice bran. The amount of N and P in the manure was 50 percent and 25 percent, respectively, of that found in ducks fed relatively nutrient-dense, village rice bran. Fish yields reflected these different nutrient inputs, with ricebran-derived fish yields being almost double those from paddy-fed ducks. However, the number of eggs produced was significantly higher for ducks fed paddy rice compared to ricebran (Figure 19).

Total collectable nutrients in the waste can exceed that present in the feed given as a night -time supplement. Natural food scavenged during the day is usually of higher food value than the supplement (Box 5.H and Box 5.J).

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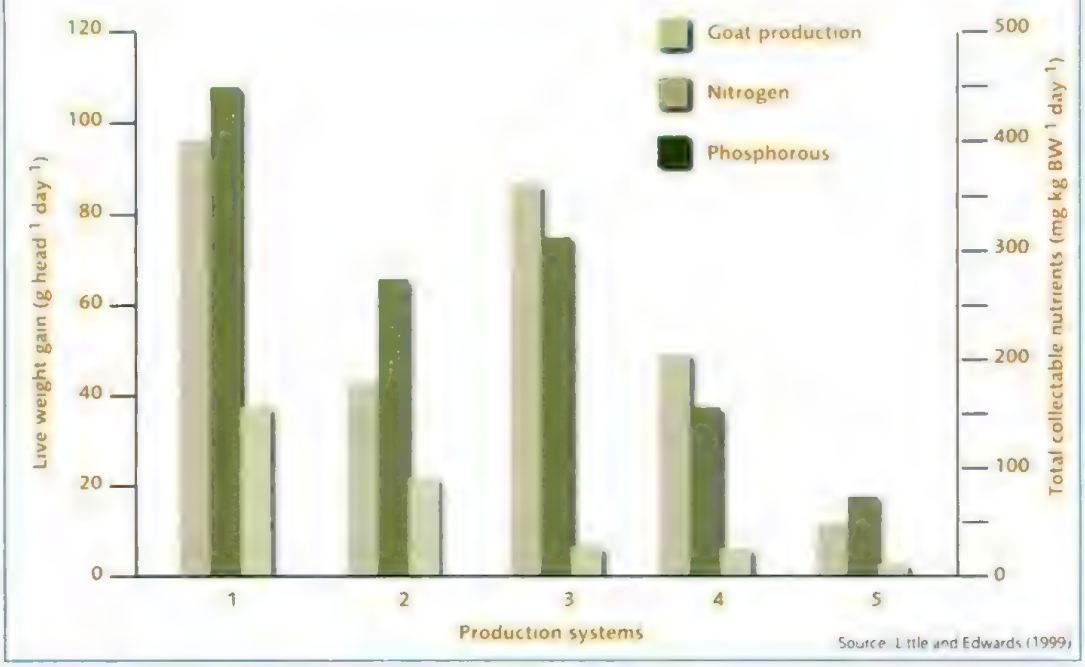
FIGURE 18

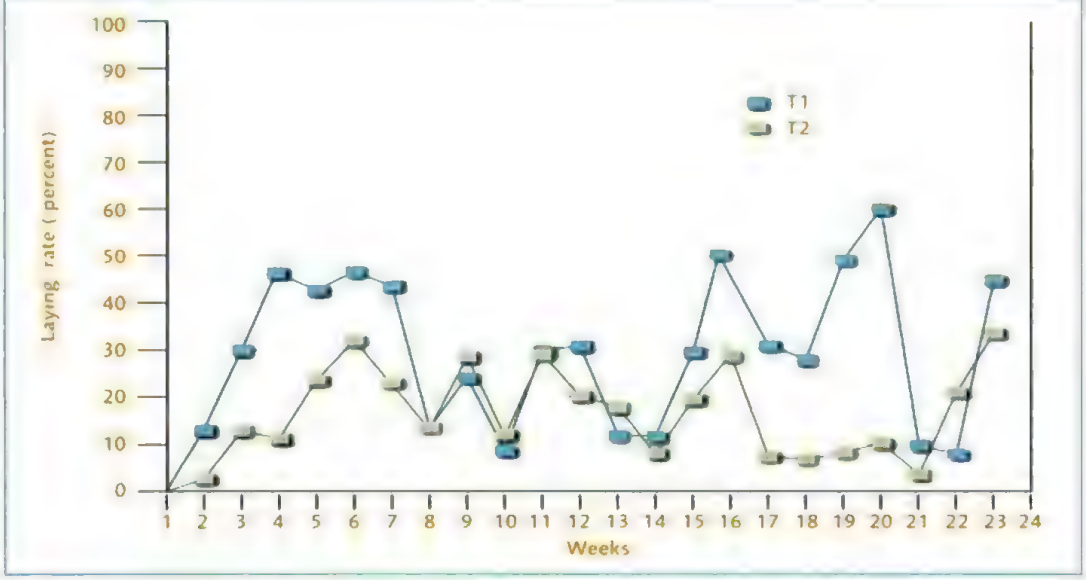
Goat production and total collectable nutrients in different management systems



Source: Little and Edwards (1999)

FIGURE 19

Egg laying rate of Khaki-Campbell x local strain ducks fed two different supplementary diets, T1=unhulled paddy rice and T2=village rice bran



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BOX 5.H

Quantity of supplementary feed affects scavenging poultry wastes and fish production

- Restricted feeding with rice bran during night-time confinement of muscovy ducks (*Cairhina moschata*) allowed to scavenge during the day reduced both the quantity and quality of collectable wastes. The level of total N in wastes declined with the level of restricted feed given from 1.28 g N duck^{-1} day^{-1}, for birds fed *ad libitum* to 0.65 g N duck^{-1} day^{-1} for ducks restricted to 50 percent of *ad libitum* feeding levels (AFE, 1992).
- Effects of both duck diet and the waste loading on fish growth were clear. A higher waste loading of ducks fed on the most restricted diets (50 percent of voluntary level) was as valuable for fish culture as less waste from ducks fed on a voluntary basis. Fish growth was similar to that from fish receiving waste from feedlot egg-laying ducks at a lower stocking density, though inferior to a pellet-fed treatment.

BOX 5.I

Integration of duck and fish production in ricefields in the Philippines

Ten approaches were compared for the management of lowland rice-fields; conventional rice monoculture, conventional rice-fish culture, rice monoculture, rice-fish, rice-azolla, rice-duck, rice-fish-azolla, rice-fish-duck, rice-azolla-duck and rice-fish-azolla-duck. Pesticides were only used in the conventional treatments. In addition to an improved understanding of the specific interrelationships within such complex systems, the study highlighted the potential benefits of integration to the stability of rice production ecosystems.

Key findings included

- Rice productivity in rice-fish systems were similar to controls but enhanced when both ducks (24-35 percent) and azolla (38-42 percent) were integrated.
- Production of Nile tilapia was increased by a factor of 0.33 with use of azolla, 1.9 with ducks and 2.2 with both. The relative impact of both azolla and ducks on the fertility of the systems also correlated with changes in oligochaete densities in ricefield soil samples.
- Egg-laying ducks raised at a density of 400 ha^{-1} were housed in pens over refuges within ricefield plots at a ratio of 12 female:male to produce fertile eggs (*balut*). The ducks were allowed to scavenge in the ricefield plot prior to rice transplantation and for periods between transplantation and flowering. Ducks were fed a commercial layer ration that was reduced by between 10-30 percent during the scavenging periods. Laying rates dropped during periods when ducks were released in the riceplots but averaged over 60 percent during the total 482 days of the trial.The presence of azolla had no effect on laying rate.
- Integration with ducks increased investment costs substantially but also yielded the highest net returns and improved income distribution through the year.
- High production costs (N-azolla was 10 times the cost of inorganic N), reduced the economic benefits of using azolla in rice production, but integration with fish and ducks improved returns.
- Ducks had significant effects on control of the golden apple snail if allowed to scavenge in ricefields pre-transplantation, especially golden apple snail.
- Azolla and ducks reduced total weed abundance by 60 and 49 percent respectively.
- Nile tilapia was ineffective at controlling snails or weeds and pond refuges appeared to increase their persistence.

Source Cagauan (1999)

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Herding of ducks in ricefields typically reduces the input of wastes into associated pond fish production systems. However extensive management of ducks remains a popular system in many places and can be integrated with fish production within the ricefield itself. Cagauan (1999) investigated the productivity of rice, ducks and fish (*Oreochromis niloticus*) within experimental integrated systems in Central Luzon, Philippines. The management of the hybrid aquatic fern (*Azolla microphylla* Kaulf. x *Azolla filiculoides*) was also investigated for its impact on fish and duck productivity and prevalence of weeds and Golden Apple snail (*Pomacea canaliculata* Lam.) in ricefields (Box 5.1)

BOX 3.1

Impacts of supplementary feed quality on waste characteristics

- **In a comparison of three different supplementary feeds (village rice bran, ground maize and ground sorghum) fed to pekin and muscovy ducks, both waste quantity and quality were affected.**
- **The degree of wastage, related to palatability and physical attributes of the feed, was an important factor but the intake and proximate composition greatly affected the value of waste for fish culture.**
- **Manures derived from maize-fed ducks were high in N, sorghum were intermediate and rice bran low reflecting the composition of the feeds themselves.**
- **Muscovy ducks were allowed to scavenge during the day and then fed one of three levels of a village rice bran ration while confined at night. Levels of nutrient in the waste were related to the amount of feed consumed. Khaki Campbell egg-laying ducks fed a complete diet while confined produced greater quantities of nutrient-rich waste (Figure 20).**

Source: Naing (1990)

Spilled feed

Spilled feed is a loss to the livestock production system but a gain to the fish because of its direct feeding value. The timing, frequency and location of feeding affect the amount of spilled feed and its direct value to fish. Feed presentation and composition, availability and design of water containers and livestock type all affect the amount or proportion of spilled feed in collectable wastes. Feedlot ducks fed complete diets appear to waste less than birds allowed to scavenge during the day and given access to supplementary feed at night. Feed processing can reduce spillage; up to 15 percent of granulated feeds may be lost compared to 10 percent if the same duck feed is pelletised (Barash *et al.*, 1982). *Ad libitum* feeding of all livestock increases spillage losses and feeder and waterer designs are important to minimize losses.

Feeding behaviour and the nature of different feeds may increase the amounts of feed available directly for fish. Waste feed left in the water container comprised more than 25 percent of the collectable dry matter from scavenging muscovy ducks fed a supplement of village rice bran (AASP, 1996)

[illegible] FROM

Nutrients contained in manure are not necessarily available for uptake by the food web in the pond. Indeed only a fraction is usually released in a soluble organic form, usually within the first few days of adding the waste to the pond (Knud Hansen, 1998). Cumulative nutrient release curves for buffalo and duck manure indicate that the nutrients within manure from poorly-fed ruminants are relatively unavailable compared to monogastrics fed high quality feed Manures with high levels of material resistant to decomposition may quickly build up in the sediments, requiring frequent removal

[illegible] ION AND

Animal waste quality can be drastically affected by the method of collection and storage prior to

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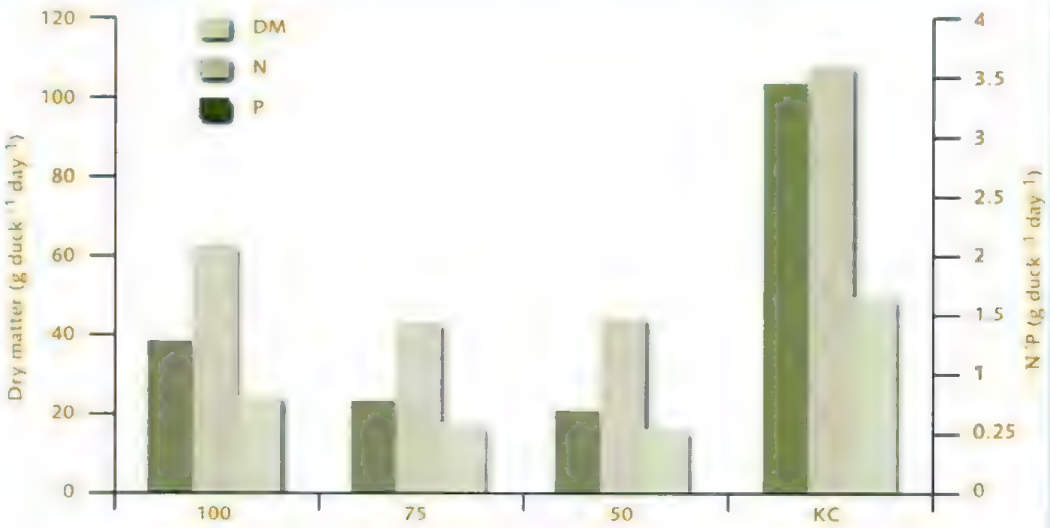
FIGURE 20

Dry matter (DM), total nitrogen (N) and total phosphorous (P) in wastes of ducks

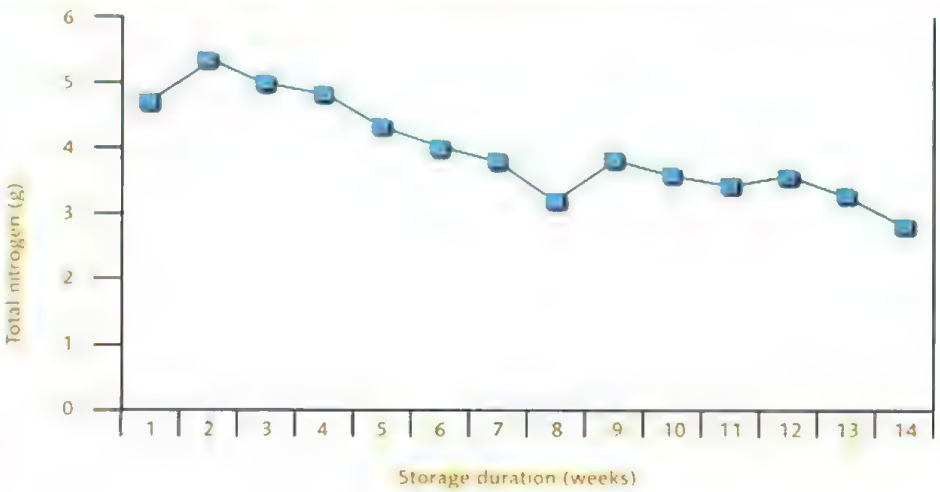


50, 75 100 were levels of restricted feeding as a percentage of voluntary intake in scavenging ducks confined and fed village rice bran at night. KC Khaki Campbell hybrid egg laying strain fed a complete diet under total confinement

Source: Modified from FAO (1997a)

FIGURE 21

Loss of total nitrogen in fresh layer manure with time



Source: Flegal *et al.* (1972) in FAO (1980)

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its use in fish culture. Bedding materials and washing water have particular influence on composition of manures, but storage condition and duration also affect their value

The use of litter or bedding is a key part of intensive livestock husbandry. High densities of animals can be kept in good health as litter absorbs moisture, reduces odor and ammonia and provides a soft floor surface. Typically bedding increases dry matter, ash, fibre and crude protein in the manure. Litter is a living community of detritus and microorganisms that varies in quality with type of substrate, livestock and its management Fermentation occurs over time and results in losses of N, volatalized as ammonia or becoming refractory and unavailable The concentration of some vitamins may increase (vitamin B12) and some antibiotics (e.g chlortetracycline) decrease with duration of storage (Chapman, 1994)

The steady decline in nutrient content of manures not collected on litter during storage is accelerated if wastes are stored under conditions of high temperature and/or exposed to wind and rain (Figure 21)

The needs of fish production for waste input may vary through the year and/or not match waste production by the livestock throughout the entire production cycle. Thus, removal and storage for later use, or sale or use elsewhere on the farm may be required. A storage pit is a common feature on Chinese integrated farms allowing strategic use of manure and prevention of overloading during seasonally cool periods.

Processing of waste, particularly through anaerobic fermentation to produce biogas, can result in concentration of nutrients as C is lost This option has been promoted as a method of reducing waste volume and increasing its value for fish culture. The reduction of BOD in waste during anaerobic fermentation means that associated aquaculture can process the wastes of greater numbers of livestock.

Overall evidence suggests that both aerobic and anaerobic storage of livestock wastes reduces their net value. Aerobic composting results in losses of N as ammonia, whereas although anaerobic fermentation concentrates N,

BOX 5.K

Summary of factors affecting livestock waste characteristics

- **Manures contain a large proportion of the nutrients in livestock feed**
- **Species, size and sex of livestock can dramatically affect the amount of manure produced by livestock**
- **Characteristics of collectable livestock wastes are affected by many factors but level and quality of livestock feed are most important**
- **Mixing of faecal and excretory waste with bedding or water tend to decrease nutrient density**
- **Wastes from scavenging livestock fed supplementary feed during night-time confinement can approach the value of feedlot-derived wastes for aquaculture**
- **Storage, especially under aerobic and high temperature conditions, leads to loss of N**
- **The value of fermentation or composting of livestock wastes on farm before use for aquaculture is often impractical and brings few advantages.**

much of it is 'bound-up' or refractory and not readily available for use by organisms in the pond's food web.

Lekasi *et al.* (2001) assessed manure management in the Kenya Highlands and found it to be critical for sustaining livelihoods of livestock-dependent people. Smallholder dairying was particularly important and the major conduit for import of external nutrients onto farms through purchase of feeds and supplements Farmers had many ideas for the better management of manures but few were implementing them, especially urine conservation. Manures were also bought and sold at prices above their nutrient value alone, indicating the value farmers placed on the physical benefits to soil quality

Above
Backyard pig production in Northeast Thailand has been limited to households who can obtain sufficient rice by-products. Greater availability of complete feeds and better transportation systems is opening up further opportunities for backyard production

Below
Washing waste duck feed from the waterer into fishponds nearby. This is a high quality pond input

5.3 WASTE ADDITION

Maintaining optimal levels of nutrients and water quality condition to meet the needs of pond food web organisms, fish and other components of the farming system requires an understanding and application of basic concepts rather than a recipe. Best fertilization practice is rarely based on fixed levels of nutrient inputs (or numbers of livestock per area of pond) because both the requirement of the fish culture system and the availability of waste are likely to vary. Nevertheless, for the tropics, upper levels of animal numbers per unit area of fish pond can be given, assuming standard feeds and size of livestock and, a need to maintain aerobic conditions (Little and Muir, 1987).

Systems designed for easy removal and use of livestock wastes, allow the most complete integration of livestock with fish, resulting in the least loss of nutrients and their most efficient use in aquaculture.

Livestock pens should be designed for easy collection and removal of wastes as well as high performance of the animal. The design and materials should allow for quick and complete cleaning and reduce exposure of wastes to direct sunlight, wind and rain. Livestock should be confined in a way that does not allow damage to the pond dikes. Allowing swimming birds and wallowing ruminants access to the pond dikes can result in rapid deterioration to pond structure, turbid water and loss of manure. Reinforcement of dikes with brick, concrete and synthetic sheet has been tried to prevent damage with limited impact in many cases. Limiting ducks to a cleanable pen and water surface is desirable.

Collection of urine, especially for ruminants is often overlooked and yet it contains a considerable proportion of the N. Cracked or badly designed floors of pens, although still allowing continued collection of manure, results in losses of urine.

Close proximity of the pen and fish pond generally results in more consistent transfer of wastes from livestock to pond. Sometimes pens can be situated over ponds, allowing constant

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Protecting the dikes of duck-fish ponds from damage using fences and ramps to allow access to the water

TABLE 5.3

Effect of feeding and management on waste characteristics of livestock

Poultry	System Feed lot	Scavenging	Feed Complete	Supple-mentary	Production Daily live W. gain (g/d)	Laying rate (percent)	DM
Egg laying duck	Yes	No	Yes	No	1 88	46 58	44 7
Egg laying chicken	Yes	No	Yes	No			44
Broiler chicken	Yes	No	Yes	No	32		20
Egg laying duck	No	Yes	No	Yes	0.38	16 3	[illegible]
Egg laying duck	No	Yes	No	Yes	0 42	29 8	24 8
Muscovy duck	No	Yes	No	Yes	10.4-16		40 70
	Mean values for ducks on a range of dietary regimes includes nutrients in manure, [illegible] waste feed						
Muscovy duck	Yes	No	Yes	No	Male 32		[illegible]
					Female 20		24
Growing pig	Pigs fattened on cooked rice byproducts and water hyacinth, values include [illegible] washing water						
	Yes	No	Yes	No	370		1400
Goats	Based on replicate Katjang goats (n=3) of between 17-30 kg initial weight over a three month period. Wastes removed daily unless otherwise stated						
	yes	No	Yes	No	106		453
	yes	Yes	No	Yes	62		256
	yes	Yes	No	Yes	69		[illegible]
	yes	Yes	No	No	35		167
	Yes	Yes	No	No	16.7		[illegible]

addition of waste to the pond used, which may optimize fertilization. High land costs and availability of suitable building materials and expertise are the norm for this type of system. The disadvantages include difficulties in access to both livestock and fish and in controlling waste inputs to the levels required as well as higher construction costs, particularly for pigs and large ruminants. Household pigpens in Northern Viet Nam are a major source of manure for the whole farming system. Situating the pen, with well-sloped floors and pipes close to small fish ponds, allows urine to be recycled immediately with little loss of N, and strategic use of solid waste in field crops and horticulture. Location of livestock pens close to fish ponds should consider security, all-weather access and good distribution of wastes in the pond.

Transfer of wastes away from peri-urban areas where land costs are high, to areas where fishponds can be larger and waste use more efficient, can be an advantage. Additionally, it can provide opportunities for poorer people to benefit as waste traders.

In situations where land costs are high and air-breathing fish can be economically raised, farmers may seek to exceed the normal density of livestock per unit area of pond. Alternatively they

Waste (g/animal/day) N	P	
1.97	0.49	Edwards *et al.* (1983)
1.3	1.14	FAO (1980)
0.7	0.92	Hopkins and Cruz (1982)
1.16	0.69	AASP (1996) (rice bran)
0.52	0.16	AASP (1996) (Paddy rice)
0.65-1.28	0.5-0.8	AFE (1992)
		Khalil. (1989)
1.65	0.71	
1.24	0.55	
		Long (1995)
29.1	13.6	
		Little and Edwards (1999)
7.84	3.47	Stall fed, ricebran and legume fodders
5.12	2.27	Grazing+ricebran
8.08	0.74	Grazing+legume fodder
4.57	0.57	Grazing only
1.27	0.41	Grazing only; irregular waste removal

Collecting manure from underneath roosts of village chickens for use in fishponds. Greater frequency of waste collection increase both the quantity and quality of collectable wastes

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LEFT
Large integrated meat duck-fish ponds in Taiwan are lined with bricks to reduce erosion of the dikes

RIGHT
Pigs being cooled and pens being washed down; water from fishponds is used for this task and the enriched water runs via drains back to the fish pond

BOX 5.1

Pornsak's duck slaughterhouse in Bang Lane, Central Thailand

- On first entering the duck-fish farm of Mr Pornsak it appears that duck densities are rather high for the area of ponds (<5000 m²) on the farm. Closer observation reveals that probably very little of the manure produced by the ducks is entering the ponds and that large amounts of extra feed are being given to the fish in the system.
- The operation fattens, holds and slaughters meat ducks (Pekin and Cherry Valley) especially for the restaurant trade. Between 15000-30000 ducks are on the farm at any time.The ducks are purchased in large flocks from rice farmers who have raised them by herding them through rice fields immediately after harvest for around 70 days. They have grown fast but now need to be fattened intensively in a feedlot; high quality complete feeds are given for just a few weeks in the covered sheds that gives the ducks access to the fish ponds, which are really borrow pits. In this area of former ricefields, the land must be raised to allow construction of buildings, leaving deepened areas next to the duck houses that can be stocked with fish.
- Mr Pornsak's main source of income is his daily direct sales of ducks to restaurants; income from fish is only an annual bonus and he therefore keeps his system simple. He chooses to sell most of his duck manure that rapidly builds up in his densely stocked feedlot to neighbouring fruit farmers. The amount of duck manure would greatly exceed that required to fertilize his limited area of fishponds for low-value herbivorous fish. He therefore stocks a species of carnivorous river catfish (*Pangasius hypophthlamus*), that can be raised at high density and is tolerant of poor water quality. They require feeding to reach marketable size (>1 kg) within a year and disposing of whole ducks that die before they reach the market size in the fishpond is convenient. Mr Pornsak has no harvest equipment and therefore sells the fish to middlemen who drain the ponds and harvest his fish annually; he receives a fixed price per kilogram. Only a small proportion of total income is derived from the fish component of the farm (<2 percent), compared to processed ducks (88 percent) and feathers (10 percent). Manure sales bring negligible returns but the characteristics of the operation prevent more on-farm recycling of manure to fish.

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may add feeds or fertilizers to supplement animal production wastes (Box 5.L). More normally livestock waste is insufficient to optimize fish production, because of risks or costs associated with intensive livestock husbandry or problems managing the waste or because of the limited resources of small-holders.

When livestock and fish are raised within a broader farming system, experienced farmers design the integration to more closely match their overall needs. The cost of complete nutrient collection may be too high. Concrete floors that allow collection of urine and washing water may not be affordable, or the high cost of nutrients may require manures to be used elsewhere on the farm (Box 5.M).

BOX 5.M

Surin's use of duck manure in Nakon Pathum, Thailand

Lung Surin integrates a flock of 1500 egg-laying ducks with fish and fruit production on his farm in Nakon Pathum, Thailand. He chooses to use duck manure relatively extensively for fish culture (total area of ponds more than 2 ha) rather than optimize the production of fish alone. His strategy allows him to reduce the production costs of eggs, maintain duck health and also to use manure for horticulture. Rice is double cropped in the area, presenting opportunities several times in the year to suspend complete feeding and allow ducks to forage for food at low cost in the surrounding fields. The ducks also scavenge in the margins of the very large ponds year-round, which maintains their condition. Ducks raised in feedlots at high density are more prone to stress-related illness. In addition to the natural feed that the ducks scavenge, he optimizes egg production through using a high quality feed that he mixes himself. One of the methods that he uses to maintain duck feed intake, a key parameter of productivity, is to offer the feed as a moist mash frequently during the day. At the hottest time of the year, he also feeds during the night when temperatures are lower. Leftovers from each feeding, which quickly become unappetizing, are washed into the pond for fish. Additionally he uses pig manure purchased from a neighbouring farm and various supplementary feeds if available.

BOX 5.N

Factors affecting characteristics of livestock waste and its use for aquaculture

- **Type of animal (size, growth rate, feed and growth efficiency, sex).**
- **Housing (open, closed).**
- **Manure used fresh or collected, stored and transported (CST).**
- **Nature of bedding materials (bulk density, particle size, moisture retention capacity, compressibility, penetrability, hygroscopicity, biodegradability).**
- **Quantity of bedding or cleaning materials per surface unit (nutrient dilution, microorganism activity).**
- **Inclusion or exclusion of urine.**
- **Nature of ingredients in feed (digestibility, nutrient density and composition).**
- **Feeding method and presentation; *ad libitum* or restricted; as a dry mash, wet mash, pelletised for concentrate diets or whole, shredded for leafy diets.**
- **Litter management (regular/irregular removal).**
- **Type of waste storage (aerobic, anaerobic, exposure to temperature, rain, wind).**

Source: Modified after FAO (1980)

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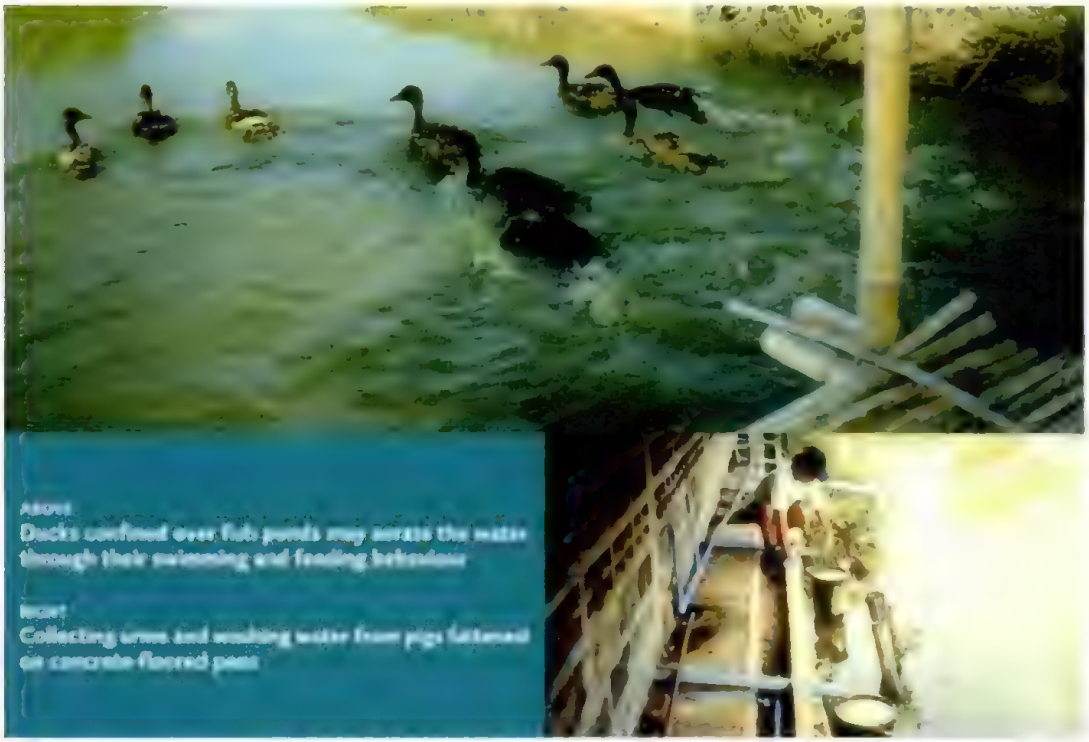

Above
Ducks confined over fish ponds may aerate the water through their swimming and feeding behaviour

Inset
Collecting urine and washing water from pigs fattened on concrete-floored pens

BOX 3.0

Questions to ask during the design of livestock–fish systems

- What is the demand for and value of the livestock and fish species to be produced?
- What are the production cycles of the fish and livestock species? How does waste production by the livestock vary with time?
- Are there any variations in ambient temperature throughout the year?
- What is the feeding niche of the species to be cultured?
- What is the sensitivity of the desired species to dissolved oxygen level?
- What is the value of livestock waste[1] compared to farm-gate prices of fish, inorganic fertilizer and supplementary feed?
- Has the waste been stored or mixed with other materials. If so what effect has this had on nutrient concentration and availability?
- Could the wastes have become contaminated during production, storage or transfer to the pond with substances harmful to fish or natural food webs?
- What proportion of the wastes (solid and liquid) produced are available for collection/use in fish culture?
- What is the C:N ratio of the waste to be used? Is it in the right range to allow adequate water quality to be maintained at the loading used?
- Are other nutrient inputs (feed, fertilizers) to be used in the pond? If so, what is the total expected dry matter loading?

[1] Opportunity cost for use elsewhere on the farm (field crops, horticulture), sold off or used for biogas production

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6

Public health and livestock–fish

The public health implications of livestock–fish integration are investigated in this chapter. Many of these are as important for specialized, stand-alone livestock and fish production as for integrated systems. Historical associations between human health and livestock production are compared to modern threats and how a large range of inputs to livestock, fish and wider food production systems may impact directly or indirectly on public health. Identifying the hazards and assessing the risks of pathogens including bacteria and viruses and parasites, are considered, and the involvement of integrated farming in influenza pandemics is discussed.

The importance of both chemical and biological hazards is raised. The current debate about antimicrobial resistance is interpreted from the standpoint of extra risk due to integration. Relative risks from bioaccumulation and toxic algal blooms are discussed.

General considerations

Public health issues can be considered as those of direct importance to both producers and consumers of fish and include broader issues of food production, processing and delivery systems. Linkages have been made between fish or livestock production and health in terms of communicable diseases, non-communicable disease, malnutrition and injury (Birley and Lock, 1998). Clearly, the improved availability of low-cost fish and livestock products for people's nutrition needs to be placed in perspective with likely risks.

Threats to public health from both livestock and aquaculture are diverse. Recently, livestock and fish have been implicated in the irregular occurrence of influenza pandemics; the global impacts on public health of promoting livestock and fish integration are huge if these claims are

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substantiated. Certainly throughout history, infectious diseases have largely entered human populations through animals (Morse, 1990). It has been known for some time, that common pathogens of warm-blooded animals do not generally cause disease in fish (Guelin, 1962 cited by Buras, 1990), but the role of cultured fish in the possible transfer of pathogens between livestock and humans is important, particularly in less developed countries.

Producers and consumers in developed countries are not immune, however, as the increasing number of food scares indicates and the global food trade continues to expand. Both the resurgence of 'old' risks, such as the recent outbreaks of anthrax in Australia and Thailand, and newly identified problems such as BSE in the UK show the interconnection between the health of humans and their food. The recently identified problem of *Streptococcus iniae* in tilapia in North America also raises the spectre of food hygiene becoming a major political issue, complicating the promotion of new aquaculture species by new producers.

Livestock and fish are involved in both passive and active transfer of a range of parasites and diseases to humans, broadening the need for risk assessment. The role of fish and warm-blooded livestock as intermediate hosts for a range of human parasites and control strategies are well known. However, the increasing use of a range of technologies, chemicals and feed ingredients in both livestock and fish production poses a relatively new set of risks. Products such as anti-microbials, pesticides and a range of chemotheropeutants are often used with little idea of either indirect or long-term risks. Prophylactic use of antibiotics and growth promoters in intensive fish feeds rival their use in the livestock industry. Similar problems, in terms of public health and consumer resistance, have arisen with legislation governing the use of these compounds in different countries threatening international trade. The development of genetically modified organisms, either as feeds of livestock and fish, or the animals themselves has been raised as both a moral and public health issue.

A holistic, balanced assessment of risks involved with integrated livestock-fish production needs to consider the alternative and more specialized, separate intensive systems. An example is the impact of livestock and fish culture on water quality as independent or integrated activities. Pollution of surface and ground water, with direct negative impacts on health may be avoided if wastes are recycled through integrated aquaculture with little to no impacts. The pooling of water has often been related to the spread of insect-vector borne diseases but use of water for aquaculture may reduce this risk. Unmanaged water bodies in rural or peri-urban areas are more likely to harbour suitable micro-habitats for hosts' pests than ponds stocked and managed for fish culture. Adoption of livestock wastes for use in fish culture may already have made important contributions to improving health and hygiene. In Taiwan, economic growth with improved sanitation and increasing livestock production have led to replacement of human waste with pig and poultry manure as fertilizers in fish culture over the last few decades.

Risk analysis, in which hazards are identified and their relevance and control methods determined, is a logical approach to assessing the implications of integrating livestock and fish production on public health. An attempt is made to identify the hazards associated with the various practices constituting integrated livestock-fish and the risks associated with them.

Pathogens can affect human health through both active and passive contact. There are potential risks from handling livestock and their feeds, their production and slaughter house wastes as occur in stand-alone livestock farming. In addition there is a need to consider hazards associated with transfer and use of wastes for fish culture, in management, harvest and marketing of fish, and in addition, potential risks involved with preparing and consuming waste-fed fish.

Guidelines exist for the use of wastewater in fish culture (Mara and Cairncross, 1989) but are considered to be too conservative and overly

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restrictive. What is important is not the presence of pathogens in the farming environment but their ability to actually cause human disease. Guidelines should be based on epidemiology and not solely on presence of micro-organisms (Blumenthal *et al.*, 1991; Blumenthal *et al.*, 1996)

An understanding of the main risk factors and how to reduce them is therefore essential for developing best management practice. Moreover, in order to obtain a holistic view of risk, any comparison of public health and aquaculture produce derived from livestock waste-fed systems should be compared to those from other production systems. On a broader level, the risks associated with disposal of untreated livestock waste in fish ponds should be compared with alternative uses that may present greater risks to public health in developing countries. Fundamentally a fish pond is a treatment system for pathogens present in organic wastes; large diurnal variations in temperature, pH and dissolved oxygen in shallow tropical fish ponds tend to cause rapid attenuation of pathogens (Somnasang *et al.*, 1990) (Figure 22)

6.1.2 BACTERIA AND VIRUSES

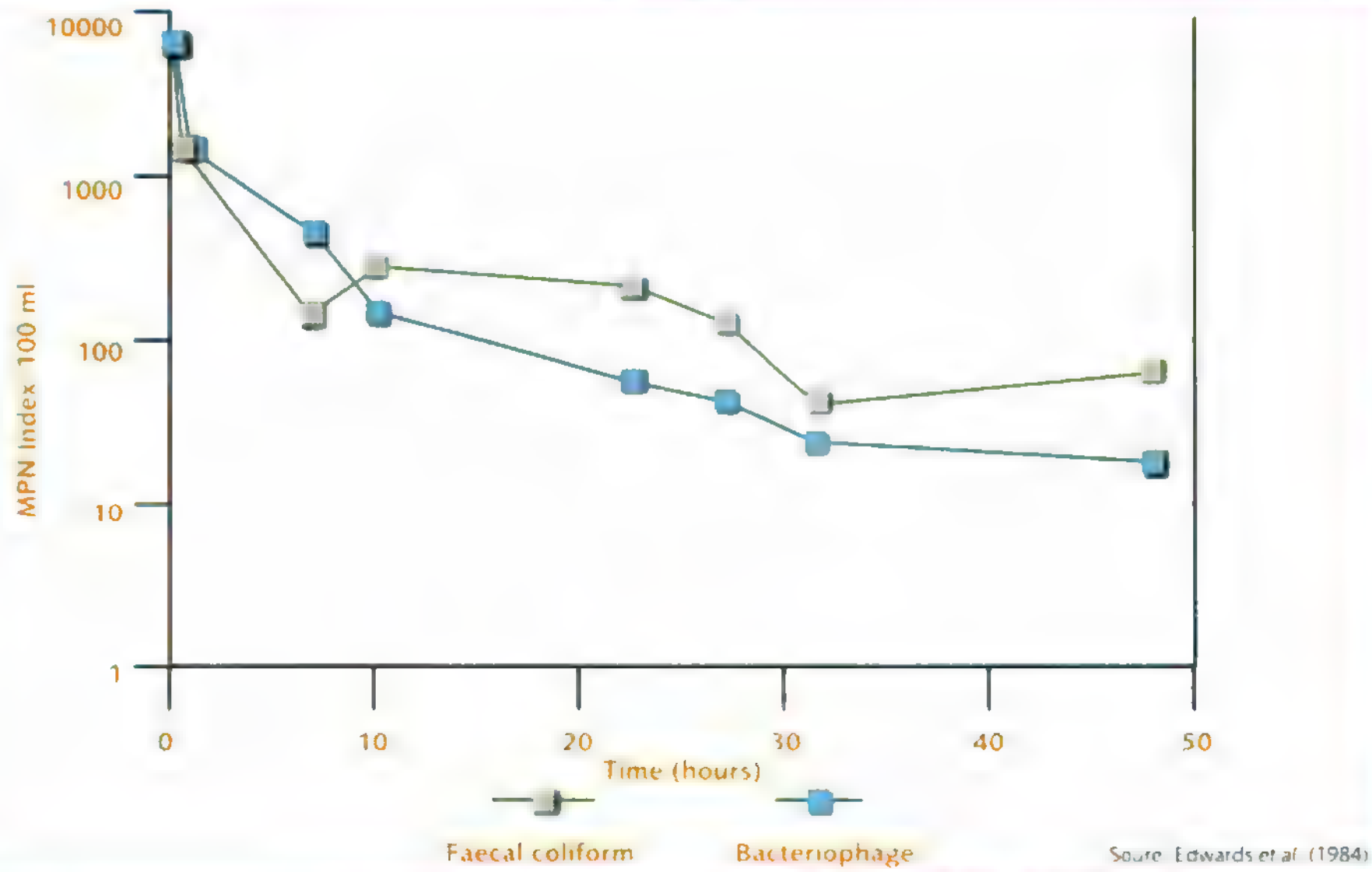
Livestock faecal wastes used as inputs into fish culture contain varying quantities of bacteria and viruses that depend on the health status of the stock and the methodology used for collection, storage and use.

Identifying hazards, assessing risks

All livestock faecal wastes must be assumed to contain pathogens. Most disease is believed to be transferred via faeces at slaughter. However, there is variation in the risk to human health based on livestock type, diet and their management. Human disease caused by many pathogens carried by livestock is difficult to diagnose. Typically, little is known about the transferability of such pathogens to humans via fish

FIGURE 22

Rates of faecal coliform (grey-green) and bacteriophage (blue) die-off in septage-loaded fish ponds



Source: Edwards *et al.* (1984)

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It should be assumed that all water used in aquaculture is potentially contaminated with pathogens, whether or not livestock wastes are used. Studies on warmwater fishponds at AIT showed that faecal coliforms, Salmonella and bacteriophage (used as an indicator of viruses) were sometimes present *before* input of wastes, suggesting that surface water is often contaminated (Edwards *et al.*, 1983, AIT, 1986) Microbial levels increased with loading level for buffalo manure added to the ponds daily, but not for the wastes from egg-laying ducks raised over the pond. In both cases, the concentration of the different microorganisms increased in the water during the early part of the experiment before falling to a constant level thereafter

The original concentrations of micro-organisms in the manure from concentrate-fed ducks were much higher than in the manure of buffalo fed a poor quality diet but phytoplankton densities were also far higher in duck manure-fed ponds.

Whilst the levels of micro-organism in manure or pond water are important in understanding risks to the producer, the level of pathogens contained in the fish at harvest is of key importance in determining risk to those preparing and consuming the fish. Levels of microorganisms found in the digestive tract of fish are much higher than in the water illustrating a likely route to infection is via contamination of hands and surfaces during preparation and cooking of fish. Buras (1990) developed the concept of threshold concentration, defined as the total number of bacteria in the fish from inspection of blood, kidney, liver, spleen, bile and digestive tract that causes appearance in the muscle. This was developed after exposing various species of fish to different levels of micro-organism in the water and then determining the levels present in various parts of the fish. Above a critical level, the immune system of the fish cannot cope with bacteria levels in the water, leading to their presence in various organs and, finally, muscle. Buras (1990) found that aggregate levels of total bacteria present of between 1.0-2.0 x 10^4 (Standard Plate Count, SPC) to be the **threshold concentration** for common carp. The concentration of bacteria in water that is required to reach these threshold values (**critical concentration**) varies between 1.0 and 5.0 x 10^4/ml, which would require loadings far in excess of that required for optimal fish growth.

At loading rates of manure investigated in the AIT trials which maintained good water quality and led to optimal fish yields, the threshold concentrations were clearly not exceeded as the indicator micro-organisms were rarely found in organs and were never found in muscle. *Salmonella* are commonly found in surface waters in nature, with contamination from wild birds a likely source. However, conditions are such in waste-fed ponds that even heavier microbial loads from introduction of livestock manure are rapidly attenuated. *Salmonella* has also been found in shrimp pond sediment and shrimp throughout Southeast Asia however, and the cause attributed to the use of large amounts of fresh chicken manure and supplementary feeds (Reilly and Twiddy, 1992).

In contrast to bacteria, indicators for pathogenic viruses, such as bacteriophage give a measure of faecal contamination rather than the presence of pathogens. It is thought that enteric viruses are also rapidly attenuated in waste-fed ponds but their low infective dose suggest that serious attention be given to their persistence in fish ponds.

Reducing risks

Risks of passive transfer of pathogens through handling of live fish during production, harvest and processing can be reduced if physical exposure is minimized through use of appropriate clothing, especially gloves. Attention to minimise the risk of cross-contamination during processing should be avoided, as the digestive tract is the major source of pathogens Depuration, the holding of fish in clean water without feeding, facilitates this task by reducing the amount of digestive tract contents.

Consumption of raw, certain types of processed, or undercooked fish should be avoided. Removal of visera and major organs, in addition to the digestive tract, prior to marketing 'whole fish' would also reduce risk

Pre-treatment or processing of livestock waste prior to its use as a fishpond fertilizer or feed ingredient also reduces risks associated with transfer of pathogens. A comprehensive study of shrimp farms in Southern Thailand found no evidence of *Salmonella* (Dalsgaard *et al.*, 1995). A critical factor for the survival of *Salmonella* appears to be adequate moisture. In a subsequent analysis, *Salmonella* was not found in chicken manure samples used in shrimp farms, as they tended to be sun-dried or dry pelletized (Dalsgaard and Olsen, 1995).

Depuration may not always be an effective method to remove micro-organisms from fish Buras (1990) found that when common carp was cultured in heavily polluted water, depuration in clean water for a six week period was ineffective because the micro-organisms had already entered the muscle tissue. The process was more effective with tilapia raised in optimal growth conditions in wastewater-fed ponds as they contained initially lower concentrations of bacteria, with none present in organs or muscle.

Streptococcus sp. infections of fish are a relatively newly identified threat to humans. Increasingly found in cultured tilapias, *S. iniae* and other *Streptococci* that infect fish may also infect humans. Infections have been contracted when people market live fish, or consumers are cut or spined during handling or preparation of the fish. The disease appears most prevalent in intensive tilapia production systems, in which water quality is marginal and/or there is environmental stress or trauma to the fish (Plumb, 1997). It has not yet been associated with fish from integrated culture systems.

6.1.3 PARASITES

A variety of parasites (Trematodes, Nematodes, Cestodes) may be transfered through livestock waste to aquatic plants and animals (fish, amphibia, molluscs or aquatic vegetables) and then back to humans. A list of species known to be carried by fish that affect humans is given in Table 6.1

An understanding of current systems and the potential reduction or increase in risk through integration is required. The exposure of livestock to parasites, through foraging on human faeces is often a critical part of the life cycle in lesser developed countries lacking adequate sanitation but if animals are penned, risks are minimal. The risks of promoting integration of pigs and fish among groups in which pigs are allowed to forage on human waste may, in contrast, be important (Box 6.B)

Certain feeding practices may appear to increase the risks of infection of livestock integrated with fish production Water plants that can be harvested opportunistically in waste water drains or raised purposefully in water contaminated with human faecal matter for livestock feed are often accompanied by attached

BOX 6.A

Key points to reducing public health risks from apthogens in livestock-fish systems

- **Good husbandry of the livestock, an adequate level of nutrition, hygienic accommodation and control of scavenging on human waste.**
- **Storage and/or composting of wastes reduces pathogens and parasites.**
- **Water quality suitable for optimal growth of fish contains bacteria below the critical concentration that lead to infection of fish organs and muscle.**
- **Fish digestive tracts typically contain high levels of bacteria.**
- **Although depuration is not effective when bacteria occur in fish muscle, holding fish for a short time after harvest effectively reduces bacteria in the digestive tract.**
- **Contamination of hands and surfaces during cleaning and evisceration of fish is a common route of pathogen infection through cross-contamination of other food.**
- **Adequate cooking of fish ensures fish is safe for human consumption; fish eaten raw, undercooked, or improperly processed or preserved increases risk.**

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BOX 6.8

Safety issues as aquaculture stimulates changes in household pig production in Lao PDR

Pigs are the most economically and socially important livestock raised in Hmong communities in upland Lao PDR. These people are an ethnic minority with little access to the market, educational or health resources living in one of the ten poorest countries in the World. The use of pig manure to fertilize ponds from overnight confinement of the pigs is becoming more prevalent, highlighting issues relating to safety and sustainability. A multidisciplinary approach to ensuring success and safety of the developing systems is required. Penning the livestock without consideration that the pig diet now lacks certain nutrients can result in failure of the system and a return to traditional practice. However, if significant advantages are perceived through reuse of the pig waste in fish culture, this should consolidate improved and more sanitary approaches to pig production. Development agencies should focus on educating pig producers on how to maintain their animals free of parasites e.g. *Fasciolopsis buski*, *Clonorchis sinensis* and optimize the use of wastes. Consumers should also be targeted to improve understanding of hygienic preparation and consumption of both pork and fish.

Source: Modified from Oparaocha (1997)

molluscs and other invertebrates which are commonly intermediate hosts of important parasites. Increased rates of infection are unlikely via this route, however, as livestock are normally infected by a different stage of the parasite found in the faeces of humans. The integration of backyard pigs raised partly on uncooked water plants was implicated in the former widespread occurrence of *Fasciolopsis buski* in Central Thailand however. In some cases household pets can be reservoir hosts (e.g. *Clonorchis* and *Opisthorchis*)

TABLE 6.1

Main types of parasites. Source: Modified fro

Species	Reservoir hosts
Trematodiases *Clonorchis sinensis* (Chinese liver fluke)	
Trematodiases *Opisthorchis viverrini* and *O. felineus* (cat liver flukes)	Humans and cats
Trematodiases Paragonimiasis	Humans and various mammals
Intestinal Trematodiases e.g. *Heterophyes*, *Metagonimus*	Humans
Nematodiases *Gnathostoma* *G. spinigerum*	Humans, cats, dogs
Nematodiases *Capillaria philippinensis*	Migratory birds, humans
Cestodiases *Fasciolopsis buski*	
Fasciola hepatica (liver fluke)	Humans, sheep, cattle,
Gastrodiscoides *Schistosoma* spp	Monkeys, pigs, rats Some species have water buffalo, cattle, dogs and rats

Edwards (1992) and WHO (1999)

Intermediate hosts/habitat	Possible additional impacts of integration	Notes
Snails especially *Parafossarulus manchouricus* 80 species, including 70 cyprinids are reported as hosts. Many are important cultured species	• Feeding small, raw fish to pigs as a protein source could encourage re-infection • Use of cooked small fish for livestock feed instead of direct consumption by humans could reduce risk • Replacement of overhung latrines/use of fresh nightsoil with livestock manure could reduce risk • Increased productivity of waste-fed ponds could result in more fish eaten preserved rather than fresh, increasing risk	Mainly occurs in China, Japan, Korea and Viet Nam Metacercariae can persist for weeks in dried fish and for few hours in salted or pickled products Killed by adequate cooking
Intermediate host a snail, genus *Bithynia* found in rice fields in endemic areas	• Feeding small, raw fish to pigs as a protein source could encourage re-infection. • Use of cooked small fish for livestock feed instead of direct consumption by humans could reduce risk • Less reliance of seasonal wild caught fish (often preserved) most linked to infection could reduce overall risk	Laos, Thailand, Poland, Eastern Europe No cultured cyprinids are known to be important in as hosts-mainly wild cyprinids
Intermediate host are snails that vary with locality and crustacea	• Replacement of wild crustacea with farmed products in the diet could reduce incidence	China, Ecuador, Japan, Korea, Peru, West Africa Very common
Freshwater snails *Barbodes gonionotus* infected in Northern Thailand with *Haplorchis* spp.	• *B.gonionotus* often raised in polyculture in waste-fed systems	Korea, Egypt, Japan, Philippines,Thailand
Low host specificity; Cyclops (zooplankton),fish (snake-head), frog, snake	• Snakehead, catfish, eel and carp harbour the nematodes, but there have been reports linking the disease with products of aquaculture	Thailand, Viet Nam
Small freshwater fish	• No reported links with aquaculture	Columbia, Egypt, Indonesia, Iran, Italy, Japan,Philippines, Korea, Spain, Thailand Spread through bird faeces
Freshwater snails, water plants	• Feeding of aquatic plants to pigs may pose a risk • Confinement of pigs to allow integration with fish culture could reduce incidence	Asia, Eggs appear to be resistant to heat so thorough cooking required
Freshwater snails, water plants		China
Water plants Freshwater snails	• Improved management of fish ponds may reduce incidence through reduced habitat and host • Closer integration between ducks in integrated fish culture could control snail hosts	Bangladesh, India, Philippines, Viet Nam Transmissions of eggs through both faeces (*S. japonica* and *S. mansoni*) and urine (*S. haematobium*)

Source AIT (1986)

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In Southeast Asia where helminth-related health issues are most important, aquaculture typically develops from more extensive, and often community-based, aquatic resource management. Stocked and wild fish are often present in the same systems and thus risks associated with greater infection with *Opisthorchis*, which is present only in indigenous cyprinids (WHO, 1999), could be magnified by promoting integrated aquaculture

Reducing risks

Improved sanitation or human waste disposal is a key element in the control of parasites, as is the control of pond-side vegetation that provides cover for snails which are often intermediate hosts. Education and the availability of anti-helminth drugs are also prerequisites for successful improvement of public health at the community level.

Aquaculture may also reduce the health impacts of parasite diseases. Key aspects of this are through habitat modification and host control

Although most fish species have been found to be relatively ineffective at biological control of snail intermediate hosts (McCullough 1990) snail-eating black carp (*Mylopharyngodon piceus*), and ducks can be managed to control them to a limited extent. The Louisiana red swamp crayfish (*Proambarus clarkii*) is being used in an attempt to control freshwater snails in Kenya (Hofkin *et al.*, 1991) Abandoned or poorly managed fish ponds have been associated with schistosomasis in Africa (McCullough, 1990) but well managed, productive systems in which aquatic weeds and molluscs are removed or managed are probably less of a problem

Poorly-managed fish ponds often become mosquito-breeding sites (Birley and Lock, 1998). Removal of surface and emergent vegetation, as a part of intensified aquaculture, reduces shelter for mosquito larvae. Introduction of aquaculture has actually decreased the incidence of disease through reduction of the habitats of the vectors or intermediate hosts such as mosquitoes and snails in Israel and China respectively.

A major issue regarding the promotion of integrated livestock-fish production has been the possible connection between such practices and the emergence of influenza pandemics, a link which has led to heated debate in both the scientific and popular literature (Scholtissek and Naylor, 1988; Edwards *et al.*, 1988; Edwards, 1991; Skladany, 1996). It has been claimed that the farming of pigs, poultry and fish together on the same farm is predisposing Asia, and the world, to the emergence of new virulent strains of influenza virus. Human influenza viruses are similar to poultry viruses but require change before they can infect humans, a change that can occur in pigs or between chickens and ducks (Li *et al.*, 2003). Recent evidence suggests that not all human flu pandemics started in Asia, nor are they related to avian viruses. The outbreak of Spanish flu, which killed 20 million people in 1918-19, is believed to have started in the US, and recent analysis shows that the strain is unrelated to poultry and closer to a pig virus (Taubenberger *et al.*, 1997)

The known possible transfer of such viruses from poultry to pigs, which act as 'mixing vessels' for the virus to undergo 'antigenic shift' is not questioned by aquaculturists, but rather the role of aquaculture in the process. Modern, integrated systems in which both poultry and pigs are raised together on the same farm with fish, are rare for fundamental economic reasons, whereas traditional farming of poultry and pigs together on farms without fish is common throughout the developing world, and especially in China. Home to many of the world's poultry and pigs, China is also the putative origin of new strains of influenza Where markets and production systems are intermediate between backyard and commercial, many 'hybrid' systems do exist however. A recent study in the environs of Ho Chi Minh City found that although pig/fish, chicken/fish and duck/fish systems comprised over 70 percent of livestock-fish systems, over 20 percent of farms with livestock and fish raised both poultry and pigs together (Nguyen and Trinh, 1998)

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Above
Farms which raise two types of livestock together on the same farm with fish are rare. This farm is using the roof area of a pig unit to shade caged egg chickens. Casual mixing of pigs and poultry is more likely in traditional systems, irrespective of whether fish are cultured

Below
Village chickens scavenging for waste feed within intensive battery egg units may spread disease

6.2 Chemical hazards and associated risks

A major issue is how integrating livestock and fish together can **reduce** the level of chemical hazards and associated risks compared to stand-alone enterprises. We first explain the range of chemical hazards with a tabulated assessment of their importance to both integrated and non-integrated aquaculture compared to, where appropriate, reference to wild stocks (Table 6.2) Generally, hazards associated with intensive aquaculture, particularly of carnivorous fish, are likely to be greater than less intensive culture of herbivorous and omnivorous species because of the greater likelihood of **bioaccumulation** and exposure through the higher levels of **water exchange** required. Wild fish in unmanaged aquatic systems may suffer more from the effects of chemicals than cultured stocks as aquatic habitats often serve to drain effluents and run-off from agriculture, and complex natural ecologies are more likely to be disturbed than closely monitored culture systems. Chemicals may accumulate more in slow-growing, carnivorous species than well-fed, short-lived farmed fish.

Exposure to chemicals can be accidental or purposeful. Contamination of the surrounding environment, water or feed source for fish or livestock integrated with fish can be either acute or chronic in nature. Chemicals are also often used as part of disease control, general husbandry or as feed additives. The tendency in integrated systems is for the fish culture component to be semi-intensive i.e. relatively low densities of fish feeding low in the food chain and these are less likely to require treatment for disease, intensive disinfection or specialized feed additives. Clearly, chemical hazards inherent in livestock production have greater potential for affecting fish in such systems than *vice versa*.

Range of chemical hazards

Chemical hazards may arise from the use of agrochemicals, chemotheropeutants, metals, feed ingredients and organic pollutants. Agrochemicals i.e. chemical fertilizers, water treatment compounds, pesticides and disinfectants are widely used in both commercial and smallholder food production. Chemotherapeutants include a range of compounds used to control the impact of disease on both livestock and fish i.e. antimicrobials, parasiticides and hormones. The issue of bacterial resistance induced through prophylactic use of antimicrobials and drug

residues that risk human health are of key interest. Exposure to metals, in addition to that from chronic or acute pollution of aquatic systems, may occur due to their use as anti-foulants and molluscides or through their inclusion as growth promoters in livestock diets. Other feed ingredients have come under recent scrutiny and, especially as use of manures as fishponds inputs may increase the pathways through which these compounds can enter the human diet, should be considered. Aquatic systems are particularly sensitive to organic pollution. In this regard exposure to chlorinated hydrocarbons that are persistent and can bioaccumulate, is of special significance (WHO, 1999).

Integrated management of livestock waste and fish production ideally leads to good practice that reduces the necessity for use of chemicals to control pests and maintain optimal conditions. The frequent collection and use of manure for fish culture can reduce problems associated with its accumulation and storage such as the spread of flying insect-born diseases or ammonia-related respiratory problems. Moreover, many farmers have found that siting of livestock pens over ponds improves the environment for the livestock through evaporative cooling; this is particularly important in the tropics where more expensive methods of controlling heat losses are uneconomic and heat stress is a major factor predisposing livestock to disease. In the sub-tropics prevention of wind-chill is often required during seasonally cooler weather.

Inland carp farms as examples of semi-intensive aquaculture often integrated with livestock production were found to have negligible use of antimicrobials (ICLARM, 1996; NACA, 1997). This is undoubtedly related to the excellent water quality and nutrition that can be maintained in semi-intensive systems, reducing the need for such inputs. The only chemicals likely to be used directly in greater quantities in semi-intensive than intensive aquaculture are chemical fertilizers, for which livestock waste often substitutes in integrated systems. However, since fish culture is typically integrated with intensive feedlot-based production, the transfer and hazards associated with chemicals present in the resultant wastes are an issue.

Antimicrobial resistance

The potential problem of bacterial strains becoming resistant to the use of antimicrobials has been raised, although rarely objectively assessed (WHO, 1999). There are two major risks of resistant strains being a hazard to human health: those associated with transmission of resistant strains from aquaculture to humans; and the possibility of non-pathogenic bacteria containing antimicrobial resistance genes being transferred to human pathogens. In the tropics, fish pathogens such *Aeromonas hydophila* and *Edwardsiella* spp. can cause human disease and the first risk, although not quantified, does exist. The second does have a potential link, particularly if drinking water is obtained from fish ponds. The risk was judged to be small as antimicrobial compounds are used to a very limited extent directly in freshwater aquaculture (WHO, 1999). However, this risk assessment disregards the large quantities of anti-microbials used both prophylatically and for disease treatment mixed with feed and water in feedlot livestock. Considerable quantities of feed and drinking water are known to be lost directly to the fish system, and the risk of survival and transfer of resistant bacteria within tropical fish ponds is a recent focus of enquiry. Although farming integrated fish has been found to increase prevalence of antimicrobial resistant bacteria in fish ponds and guts (Petersen, 2003), this is likely to be greatly outweighed by other causes of antibiotic abuse within livestock production *per se* and in human medicine (A. Dalsgaard, pers. comm.).

Bioaccumulation

The risk of accumulation of both drug residues and heavy metals in tissues of fish raised in semi-intensive systems is probably lower than fish raised intensively because direct use of feed additives and chemotheropeutants is very limited (WHO, 1999). Moreover, as water exchange is minimal in such systems, the likelihood of acute impacts from pollution incidences is also likely to be lower than for intensive systems using more water. Organic pollutants, however, may potentially concentrate in rainfed fish ponds within watersheds receiving

run-off from agricultural land in which insecticides are used, but limited data are available. It is expected, however, that pond sediments, especially in fertilized ponds, act as a sink for these compounds, reducing losses to the wider environment with consequent effects on natural systems.

As toxins concentrate through the food chain and their growth is relatively slower, wild, carnivorous fish are more likely to accumulate metals and organic pollutants than fast-growing, cultured fish.

Biological hazards

Microalgae and detrital bacteria that serve as food for cultured finfish and crustaceans produce most toxic compounds affecting aquaculture. The toxins produced by blue-green algae (cyanobacteria), **microcystins**, are particularly potent and widespread in fertilized freshwaters (Codd, 1995; Codd *et al.*, 1999). The optimal environments for raising filter feeding Nile tilapia are known to be highly fertile water dominated by cyanobacteria such as *Microcystis aeruginosa* (Colman and Edwards, 1987). The evidence suggests that not all strains of cyanobacteria are toxic and that filter feeding fish avoid ingesting toxic cells (Beveridge *et al.*, 1993, Keshavanath *et al.*, 1994). When fish losses occur, often at the end of plankton blooms, it is unclear if mortalities are related to the depleted levels of DO levels that occur or the toxic effects of free microcystins released into the water. However, accumulation of microcystins has been demonstrated in the livers of freshwater fish under such conditions (Codd and Bell, 1995). It has been concluded that the risk to human health through eating farmed finfish and crustacea containing these toxins is very small (WHO, 1999).

Indirect effects of aquaculture, especially in systems based on controlled fertilization, should consider the known effects of microcystins on livestock. The potential for contamination of livestock and human drinking water through nearby aquaculture does not appear to have been researched. The relative value of surface water as a potable source compared to alternative sources, and the potential contamination of ground water through seepage of microcystin-rich pond water, need to be better understood.

BOX 6.C

Key points to reducing public health risk due to parasites and other biological and biochemical agents

- **Reduction in risks from parasites in livestock–fish systems needs to consider current feeding and management practice and minimizing contact with intermediate hosts.**
- **Improved sanitation, anti-helminth drugs and biological control are also important.**
- **Well-managed productive ponds in which aquatic weeds and molluscs are controlled, reduce risk of parasite transfer and insect vector-borne disease.**
- **There is no evidence that livestock–fish integration has been linked to the incidence of influenza pandemics. But multi-species livestock production, especially pigs and poultry should be avoided in specialized units or integrated with aquaculture.**
- **Livestock–fish integration probably reduces the overall risk of contamination with chemicals compared to production of intensive, stand-alone fish production or fish captured from the wild.**
- **The risks to human health through microcystins produced by blue-green algae in livestock waste-fed ponds are very small. Eutrophication of any surface water, through use of fertilization, or occurring as a result of feeding fish intensively, need to consider the multipurpose use of water.**

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TABLE 6.2

Chemical hazards and associated risks to fish production

Category	Intensive	Semi-intensive Non-integrated
Agrochemicals Chemical fertilizers e.g. single compound or compound fertilizers	Little used	May be most important type of nutrient input Unknown impacts of nitrogen leaching to ground water used for drinking water source
Agrochemicals Water treatment compounds e.g. lime compounds (limestone, lime and hydrated lime) oxidising agents (potassium permanganate, calcium hypochorite), flocculants (alum, zeolite, gypsum) lime, hydrated lime, Osmoregulators (salt, gypsum)	Little risk	Little risk
Agrochemicals Pesticides-mainly used in ponds Algicides e.g. copper, triazine herbicides)	Used in channel catfish ponds to control microplankton little effect	Polyculture of filter feeding fish obviates the need for their use
Piscicides mainly used to control competitive or predatory wild fish e.g. teaseed cake, mahua oil cake, rotenone, urea, lime, phostoxin		Commonly used in pond culture
Insecticides mainly used to control competitive or predatory insects and zooplankton*	Used most intensively in intensive nursery pond production	
Agrochemicals Disinfectants e g benzalkonium chloride, polyvidone iodine, gluataledehyde. Formalin, hypochlorite	Used most in intensive systems for disinfection of equipment and holding units	
Chemotherapeutants Antimicrobial agents Antibiotics eg oxytretracycline, oxolinic acid, amoxicillin, co triamazine, flumequine	Controlled use in some countries; Few controls and commonly used in intensive fin fish and shrimp production in Asia	Very little used (<5 percent)
Chemotherapeutants Parasiticides e.g.organophosphates	Particularly important in cage-based systems where fish are raised at high density	Not widely used in pond-based aquaculture, althou
Chemotherapeutants Others e.g. hormones	Hormones used to induce spawning but very small quantities which can be control, especially in the tilapias, and large hatcheries may produce relatively juvenile stage and rapid excretion rates suggest there is no risk. Impacts on negligible as little water exchange required	
Metals Antifoulants and molluscicides e.g. copper sulphate	Particularly important in intensive systems	Used in pond preparation, often with lime which prevents high concentration in water. Bioaccumulat not a problem in fish but could be in shellfish
Tributyltin	Salmon have been shown to accumulate	Used in rice production to control Golden Apple Sn with negative health impact on livestock and huma (Halwart, 1994)

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Integrated	Wild stocks	Notes
If animal manures are not limiting, unlikely to be important	Use in agriculture may impact on unmanaged aquatic systems affecting biodiversity. sensitivity to toxic algal blooms	
Little risk	Little risk	Handling hydrated lime
Polyculture of filter feeding fish obviates the need for their use		Unlikely to present a serious risk under normal conditions but available data base is insufficient to permit a definitive statement. Some persistent insecticides (organo-chlorines) are known to be used. Use by young people without proper information or protection poses a real threat to their safety. Natural products may be more toxic than synthetics.
Commonly used in pond culture		
Organophosphate and pyrethroid insecticides used in livestock production pose a threat to fish if washed into ponds with wastes		
Widely used to disinfect livestock units, may contaminate wastes and/or be disposed of in ponds. Limited database on effects		
Very little used in fish but present in waste feed, and as residues of digestion (faeces) and metabolism (urine) in livestock waste		
can be used for ectoparasites		Principle health hazard to people working with the products
rapidly excreted. Steroids used for sex large quantities But only used at the receiving water are also likely to be		Handling of all hormones should be carried out using normal precautions and should be limited to facilites where this can be ensured

(Continued on page 98)

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TABLE 6.2

Chemical hazards and associated risks to fish production

Category	Intensive	Semi-intensive Non-integrated
Metals Pollutants from acute or chronic pollution	Bioaccumulation suggests that intensively raised fish fed high levels of fishmeal are likely to have higher levels of methyl mercury	Lower risk of bioaccumulation in herbivorous/ omnivorous fish. Fast growing fish harvested young also likely to have lower levels. High pH, increased hardness and high content of soluble and suspended organic compounds that are typical of pond aquaculture, reduce mercury uptake Unknown risk of chromium contamination of fish ponds in Calcutta
Feed Ingredients Dependent on a series of steps from growing and harvest of feed ingredients to ingestion by the animal Includes additives and contaminants	Large numbers of additives, often used in small quantities, used in complete formulated feeds Fish oils particularly likely to have high levels of chlorinated hydrocarbons-mainly used in intensive mariculture	More likely to use locally available ingredients. Maybe fresher,or stored under poorer conditions and contaminated by mycotoxins
Organic pollutants Acute and chronic pollution e.g. chlorinated insecticides and their degradation products PCBs Dioxins and furans	Contamination of feedstuffs, e.g. in 1994 one third of channel catfish contained high levels of dioxin	Fish raised in wastewater containing industrial chemica chlorinated pesticides Such fish may become unmarke high health risks occur High levels of dioxin and PCBs in livestock feed ingred Edwards, 1999) Fish raised with a high fat content are likely to concen-

	Wild stocks	Notes
Integrated		
Slow growing, carnivorous fish likely to have highest levels		
Risks associated with livestock diets since contaminants may be present in waste feed, and as residues of digestion (faeces) and metabolism (urine) in livestock waste		
usually show only low tissue levels of able through off-flavours before	Speculation about contamination of freshwater fish in Southeast Asia due to widespread use of Agent Orange as a defoliant. (Schecter *et al.*, 2001)	With the exception of chlorinated hydrocarbons-most industrial chemicals and agrochemicals are degraded Global distribution of dioxin: tend to accumulate in colder climes and reduce relative concentration in tropical waters
ients are occurring regularly (Little and		
trate these compounds		

Source Modified from WHO (1999)

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A major issue is whether algal bloom problems, and health impacts on people, are more or less likely to occur in fish culture systems integrated with livestock waste than either intensive, stand alone aquaculture or infertile extensive systems. Intensive fish culture based on complete feeds can also cause rapid and sustained eutrophication. Clearly, promotion of waste-fed aquaculture requires consideration of the overall water needs of households

Summary

The use of human and livestock waste in semi-intensive fish culture, subject to certain safeguards, can generally be considered positive in any holistic assessment of risk (Edwards, 1993). Semi-intensive systems fertilized within the carrying capacity of the system are healthy environments for fish. The fish production unit can act to 'treat' wastes that themselves may contain pathogens, provided certain precautionary steps are observed. Moreover, non-integrated intensive livestock and fish production carries its own risks to public health, which should be considered in any balanced comparison

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7

Social and Economic Considerations

Improving the quality of life for the poor in developing countries will depend on reducing population growth, while improving nutrition and opportunities for income generation. Demographic trends show that many more mouths will need to be fed before human populations stabilize in most developing countries. Increased consumption of livestock products and fish are indicators of rising affluence. Meeting these needs without resorting to 'disruptive technologies' (Harrison, 1992) that together with population growth and increased individual consumption cause negative environmental impacts, is a major challenge. The appetite of growing urban centres for animal products can too often translate into environmental damage and decline of traditional mixed farming (Steinfeld *et al.*, 1997).

Both livestock and fish production can have negative impacts but if production can be integrated, benefits are likely to be more equitable and ecologically benign. Benefits of productive integrated livestock–fish accrue to producers, consumers and society in general. A crop of fish, raised at little extra cost, spread risks and diversifies livestock production. The production cost of the fish should be low since livestock waste is substituted for purchased feeds and/or chemical fertilizers, with potential benefit also to consumers. Moreover, their integration can, through a low technology approach, ameliorate the negative impacts of livestock intensification. Wastes that otherwise adversely affect surface water supplies and the people dependent on them, can be treated at relatively low cost and valuable nutrients used and retained within the farming system (Chapter 4)

Livestock–fish production has been mostly adopted by livestock entrepreneurs, often in peri-urban areas, rather than the rural poor. Better access to inputs and markets favours this group

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As developing countries become increasingly urbanized, the role of entrepreneurs in producing cheap food for poor urban as well as rural people is likely to increase. A major challenge is also to bring the benefits of integration to poorer farmers currently not producing fish at all or raising livestock and fish separately with low and inefficient production.

Fish and other aquatic animals are important both for their intrinsic nutritional value and their major role in the food security of some of the poorest people in the region. People living in Asia's floodplains have been particularly dependent on growing rice and catching wild fish, so-called 'rice-fish cultures', but are also now consuming increasing quantities of 'wheat and meat'. Urbanization and increasing wealth have stimulated these trends toward a more diversified diet. In much of Asia, however, increased purchasing power also stimulates increased consumption of fish, particularly cultured fish. Urban areas as diverse as Bangkok and Hanoi have seen rapid increases in the demand for cultured fish. While fish protein as a percentage of animal protein in the diet declines with an increase in living standards as people consume more meat relative to fish, the absolute consumption of fish tends to rise also.

The integration of fish culture within farming systems could also allow increases in fish consumption by people previously consuming little, or for whom the culture of fish has yet to develop as a viable alternative to exploiting wild stocks. This factor, together with predictions of ever increasing global trade in food, suggest that exports of both livestock and cultured fish will continue to rise. In many western countries, fish consumption is now growing much faster than consumption of meat, partly due to increased awareness of the health benefits of fish in the diet. Where aquaculture is viable in developing countries, promoting herbivorous fish raised on manure, rather than carnivorous fish species fed largely on other fish should be vigorously promoted by national and international organizations. This strategy has the best chance of meeting the needs of poor people, both producers and consumers. It can also avoid negative environmental impacts associated with specialism and separation of aquaculture and livestock production (see Chapter 4).

The use of livestock wastes to raise fish on a household level is a method for people to add value to the assets they already possess, while diversification allows poor people to offset risk. Livestock production is one of the most common methods of saving for the rural poor. Income from sale of livestock products can also be very important. Raising livestock, often on wastes and by-products, is also common among poorer people in peri-urban areas striving to balance a portfolio of different activities. If further value can be added by raising fish on livestock wastes in a water body close to the house, contributions to improved livelihoods may occur in a variety of ways. The nutritional benefit of eating cultured fish has been a major incentive to promote aquaculture, even among people who traditionally consume little. Adopting fish culture may help to develop a broader range of human and physical capital as improved knowledge and skills gained are applied more widely.

Understanding cultural norms concerning consumption of fish, and resource constraints and conflicts, is essential if integrated livestock–fish culture is to be promoted effectively more widely. The factors that drive or restrain the development of integrated farming are complex. On-farm most of these relate to constraints to the collection and use of livestock manures (see Chapter 5) but off-farm factors often dominate. Poor availability of inputs e.g. fish seed and livestock feeds, and markets may restrict interest. An 'information gap' is clearly a major constraint that needs to be addressed. Cultural and social values may also support or undermine efforts to promote integrated practices, many of which have their roots in earlier stages of agricultural development.

The promotion of integrated livestock–fish culture has been adversely affected by its complexity and the limitations of conventional extension approaches. A range of approaches that are participatory at both the farmer and institutional level show promise for greater success, providing off-farm factors remain positive and supportive.

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BOX 7.A

Summary of key points relating to social and economic issues

- **Improved nutrition through consumption of cultured fish within the household, or purchase of food using income derived from fish sales, can contribute to improved livelihoods as peoples' health and education improve.**
- **Production of both livestock and fish diversifies household assets**
- **Entrepreneurs dominate peri-urban integrated livestock–fish production, producing food mainly for those in urban-industrial communities, including the poor.**
- **Global trends suggest that the need for cultured fish and livestock will continue to increase as purchasing power and demand for diverse diets both increase.**
- **Integration with fish culture can reduce the environmental impacts that non-integrated livestock production inevitably causes, and produce high-value, low-cost food close to the market.**
- **Cultural and social values can undermine attempts to promote integrated livestock-fish production.**

7.1 Demand

Physical environments, and the cultures that have developed in them, have shaped dietary habits and the acceptability of certain livestock and fish. Taboo foods, be they pork among different groups in arid areas of the Middle East, South and Southeast Asia or fish to certain groups of people in Africa and Asia may have an important underlying basis. Clearly, the promotion of livestock or fish production to people who are disinclined to consume either would be problematic. Recent examples of crop/livestock systems evolving in Asia can all be linked to a strong market demand for the products, be it the 'white revolution' in the Punjab where intensive dairying has developed rapidly, to an expansion of the 'balut' duck egg production in the Philippines

The factors that stimulate growth of livestock or fish to be key parts of any particular farming system are complex but clearly consumer demand is critical. The comment that 'whatever the biologist may conclude about relative efficiencies of different livestock, farmers will continue to produce what the consumer likes eating, as long as he is prepared to pay for it' (Spedding, 1971) reflects richer peoples' attitudes to livestock consumption. Clearly, the major opportunities for growth in integrated livestock–fish lie with species that are culturally acceptable, profitable for the producer and affordable to the consumer. Thus, although most Asian consumers may favour freshwater carnivorous fish species over herbivores, they cannot be raised cost-effectively in waste-fed systems. The production of carnivorous fish species on trash fish and fishmeal-based pellets soon reaches a plateau in each society as demand by the wealthier people has been met. In contrast, the rise in production of fish feeding low in the food chain continues to meet unfulfilled demand for low-cost animal protein by the majority of the population in countries promoting aquaculture in Asia.

Experience shows that even new species can become popular with both producers and consumers as their relative advantages become clear. Tilapia has moved from being a weed fish rarely sold in markets to economic significance in several Asian countries. This is mainly because Nile tilapia, which also thrives in waste-fed systems, has substituted for inferior species. Tilapias have come to dominate the production of traditional carps in areas where feedlot livestock waste is abundant and its opportunity cost low such as Taiwan and Central Thailand. The popularity of integrating pigs and poultry with fish in these and other areas is based on the increased demand for a traditional food, i.e. poultry and pig products, that has grown rapidly

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with improved purchasing power. It is attractive for modern feedlot systems that produce large amounts of nutrient-rich waste to dispose of it in nearby ponds

Subsistence attitudes

Small-holders, who consume much of what they produce, have different value systems to commercial farmers and urban consumers. The rain-fed, rice-biased agricultural cycle determines both supply and demand for poultry and cultured fish products in much of rural Asia (Little, 1995) Resource-poor farmers raise different livestock for a whole range of reasons, and culture of fish is equally complex. Wild and cultured fish are often viewed very differently. In Northeast Thailand cultured fish are highly valued for their convenience during the rice harvest period when neighbours and relatives are entertained (Box 7.B). This attitude partly explains the prevailing extensive management and the practice of holding fish for prolonged periods (Chapter 8). The view of cultured fish as a 'convenience food', a similar attribute to that of home-raised poultry, which can be accessed without planning or using cash reserves is also highly valued

Both fish and small livestock meet a variety of needs, fulfilling roles defined within both 'physical' and 'social' assets used in livelihoods analysis. Any promotion of integration of livestock and fish must recognise the diversity and individualistic needs, rather than simple commercial models focusing on 'efficiency' and 'output'. Moreover, wealth, social status and gender further complicate attitudes to, and the practice of integrated farming.

The factors that affect production and consumption of fish are varied and interlinked Demographic changes point to increasing importance of peri-urban production to meet urban demand and yet aquaculture also develops in the absence of formal markets. Informal sale, exchange and use of fish as gifts are often underestimated and yet form an important component of demand that is underestimated in official statistics. In areas where wild fish are a traditional dietary staple, farmer aspirations may at first focus on subsistence but can shift quite rapidly to income generation once confidence is gained (Edwards, 1997) Natural stocks of aquatic products, including frogs, crabs and various insects were, until recently, adequate for subsistence purposes in all but the most densely settled rural areas of Asia. Undeveloped markets for these highly perishable products probably constrained commercialization (Little and Edwards, 1997)

In a similar manner to poultry, the social values of exchange and reciprocity are more important in rural areas than the cash/credit systems which dominate urban areas. Farming households raising fish may have mixed motives that include reducing costs associated with harvesting dwindling wild stocks, safeguarding food security through consumption, or sale and use of the cash for purchase of alternative, cheaper foods

Urbanization

Many of the factors driving the specialization of livestock and crop production on Asian farms are related to the two major impacts of urbanization: the creation and growth of urban markets requiring consistent supplies of food; and depopulation of rural areas that dampens demand for food produced in traditional systems (Pingali, 1995). Rural depopulation is often linked to improved infrastructure such as roads and communications; it has varying characteristics that have different outcomes in terms of rural demand. Out-migration may be either chronic or long-term, or seasonal or short-term, in nature. Communities negatively affected suffer in terms of low and erratic purchasing power and low investment in agriculture (Turongruang *et al.*, 1994; Little, 1995)

Industrial food production favours concentration near urban centres because of a range of factors. Of these transport costs and market opportunities are of greatest importance It is less costly to transport high-energy, livestock feed from distant production sites than perishable livestock products; and this encourages production, slaughter and meat processing facilities in peri-urban areas (de Haan *et al.*, 1997).

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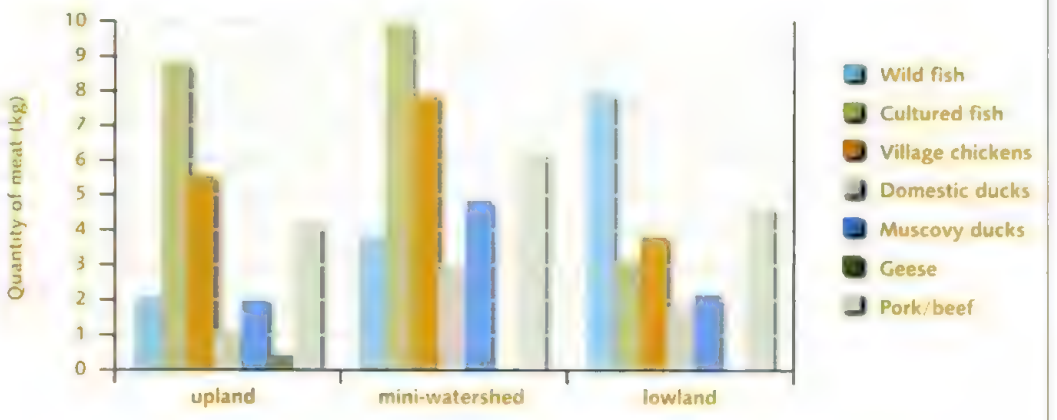
BOX 7.8

Building social assets

- Marketing of a proportion of the poultry and fish raised by small-holders is typical among farmers in Northeast Thailand. Although such sales constitute only a marginal source of annual income, poultry are valued for their role as liquid assets as they are mainly sold when cash expenditure of the household is high. The social role of poultry and both wild and cultured fish is particularly clear during the rice harvest season when meat consumption is high as friends and relatives are entertained. Cultured fish and poultry are a convenient and available high-value food used at this time.
- More than 50 percent of households in a survey of six provinces of Northeast Thailand used the fish they cultured for home consumption alone, but an important category of commercial farmer has emerged in the last decade in response to high demand for cultured fish. This minority of farmers, who are typically resource-rich, has been very receptive to use of high-input inorganic fertilization and integration with feedlot livestock.
- Households that adopt aquaculture in rural areas of Thailand tend to consume more fish and other high quality food than non-adopters (Setboonsarng, 1997).
- Poor households in Southern Viet Nam raised fish integrated with pigs primarily as a cash crop; household consumption needs were met through capture or purchase of small wild fish.



Average meat consumption per household by type during the 'feast' period around rice harvest time of farmers adopting intensified fish culture practices in three areas of Udon Thani, Northeast Thailand. Source: Little *et al.* (1992).

The trends of intensification and specialization of livestock production have been challenged on ecological and social grounds. Although intensification should ultimately improve the quantity and variety of livestock products available to urban consumers, the proportion of urban poor will grow as opportunities for livelihoods dwindle in rural areas. Increase in farm-unit size and decline in the total number of farms will increase the flow of the rural poor to urban areas, intensifying urban and rural social problems. These views have popularized the rationale for

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strengthening crop/livestock linkages through intensification of smallholder systems (Devendra and Chantalakhana, 1992)

Accessing distant markets

The development of markets, be they local, urban or international, both stimulates and controls efforts to promote livestock and fish production Local adoption of appropriate fish culture techniques can quickly lead to saturation of local markets, which in turn can stimulate the accessing of distant or even international markets. Most species of cultured freshwater fish in Asia, however, are unknown in international markets. Apart from high valued carnivorous species that have specialized markets, mainly in urban Asia, tilapias probably have most potential as a global commodity

BOX 7.D

Summary of demand-related issues

- **Demographic and socio-economic change affects demand for fish and competing products.**
- **Subsistence, exchange and use as gifts may dominate disposal of livestock and fish products rather than cash sale.**
- **Urbanization and rural depopulation greatly affect opportunities for, and nature of, livestock and fish production.**
- **Small producers of are often disadvantaged in distant markets.**

BOX 7.C

Poor quality-control hinders export of value-added fish products

Taiwan is the largest producer of whole tilapias exported to North America. The fish are raised on livestock waste and pelleted feed but poor control of product quality, and a lack of processing labour, results in most of the fish being sold as whole frozen fish cheaply to ethnic markets. Export quality tilapia, for which the largest potential markets exist, requires both significant quantities of fish large enough for processing (500-600g minimum) and commitment to the management of off-flavour problems.

Factors that support the production of export-quality tilapia include:

- **well managed pond-to-processing systems that taste-tests fish just prior to harvest and refuses unsuitable quality;**
- **facility for fattening in an intensive system and depuration prior to slaughter reduce incidence of off-flavour;**
- **low processing costs to fillets and ready-to-cook products;**
- **frozen food storage capacity.**

Product quality and uniformity become important if distant markets are to be targeted. Assembling enough fish of consistent quality from small-holders to meet the needs of distant markets is a problem, as is the likelihood of poor bacteriological quality and off-flavours

Off-flavour problems have been closely associated with freshwater fish such as channel catfish and tilapia raised in ponds or from wild stocks. Off-flavours, caused by geosmin and 2-methylisoborneol (MIB) (Dionigi *et al.*, 1998) are not toxic but can cause rejection of fish by consumers, hinder marketing efforts, and reinforce product safety concerns (Dionigi *et al.*, 1998). Organoleptic testing of tilapias raised in different systems indicates that waste-fed fish are no more likely to suffer off-flavours than pellet-fed fish, and may be superior in terms of flesh quality (Eves *et al.*, 1995). The erratic quality of Taiwan's frozen tilapia exports have hindered the penetration of larger markets for value-added products (Box 7.C).

Nutritional benefits

Fish are highly nutritious, providing animal protein containing all 10 essential amino acids in

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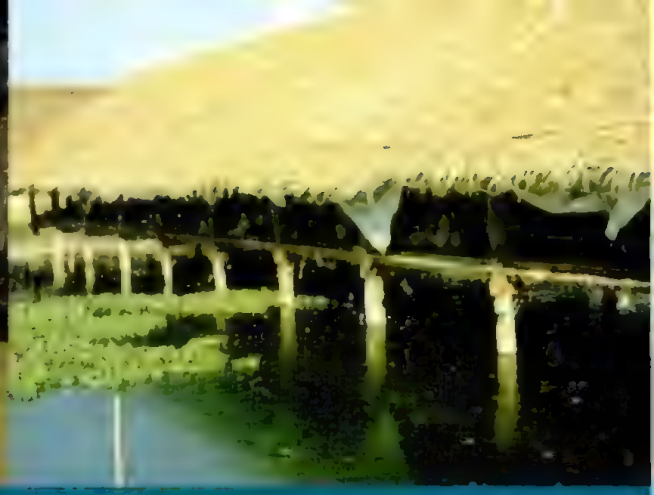

Urban markets demand large quantities of livestock products which can result in high concentrations of livestock, such as these meat ducks, being 'finished' in peri-urban areas

Pig pens constructed over ponds in peri-urban areas of central Thailand where land prices and labour costs are high

relatively high concentrations. Low in cholesterol and saturated fats, they are also rich in key fatty acids, minerals and vitamins.

Inclusion of fish in diets based on traditional high-carbohydrate staples typical of most developing countries is particularly valuable for vulnerable groups of people such as pregnant and nursing mothers, infants and pre-school children. This is partly because fish are a valuable source of polyunsaturated fatty acids (PuFAs), now known to be essential in development of the brain and nervous system and the proper functioning of the immune system. Recent research points to freshwater as well as marine fish having significant levels of these essential fatty acids (Steffens and Wirth, 1997).

The importance of fish in household food security in much of Asia has been frequently stated but on a global level fish is less important than livestock as a source of animal protein, supplying less than 20 percent of the total for developing countries. However, the average disguises the importance of fish in many of these countries, where fish meets between 40-70 percent of animal protein needs (Edwards, 1997). There is clearly a huge unfulfilled need for fish to contribute towards the livelihoods of the poor as well as the diets of the affluent (Box 7.E).

Where natural food remains abundant, cultured livestock and fish are less important (Prapertchob, 1989; Little and Satapornvanit, 1996, Edwards, 1997). In the Lao PDR small game, both birds and mammals, and reptiles and amphibians are key parts of the diet (Srikosamatara *et al.*, 1992). Foods derived from water be they insects, molluscs, crustaceans or fish contribute to a varied diet in many parts of Southeast Asia. Typically, wild and cultured food is used to meet day-to-day requirements and social occasions. Rural households in Northeast Thailand depend heavily on poultry eggs and aquatic products including fish for daily consumption, whereas poultry meat is mainly reserved as a 'feast food' for special occasions.

BOX 7.E

Nutritional importance of fish

- **In West Bengal, a rice-fish society where much of the agricultural land is flooded for a proportion of the year, market surveys indicate that consumption of fish is far more important than meat (Morrice *et al.*, 1998).**
- **In two sub-districts of Bangladesh more freshwater fish was eaten in households with little land than all meat combined (poultry, beef and mutton) (calculated from Ahmed *et al.*, 1993). Fish and chicken were the two main animal protein products produced on-farm in households with ponds, of which more than 80 percent was fish.**

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(Little *et al.*, 1992). There are important implications for household nutrition in the use of rice by-products for feeding livestock or fish, or in promoting their integration. Whereas pigs are normally marketed outside of the village, poultry meat is used mainly for feasting, and eggs and fish are consumed regularly by everyone in the household.

7.3 Gender and age

The benefits of current livestock and fish production to the household and impacts of their integration need to be analysed from the perspective of both gender and age. Traditional patterns of access and control of resources within the household may be affected by introduction of 'new' products such as cultured fish, especially if it involves reallocation of resources. Participatory tools sensitive to the needs of women have been used as part of farming system research and extension methodologies (FSR&E) to understand the importance of gender on attitudes to intensification, resource allocation and use of benefits in livestock production (Paris, 1995). Such methods are useful for evaluating the potential and impacts of integrating livestock with fish culture

Disadvantages

Introducing fish culture can potentially increase workloads for certain family members and reduce outputs of staple crops because feeds or fertilizers have been reallocated. The reproductive roles of women may limit the time they have available for extra productive activities; increasing the workload further through aquaculture could lead to overall negative outcomes on family health.

Increased labour requirements can also result in children spending less time at school, potentially undermining their future livelihood prospects. Improved access to, and control of benefits is required for women to benefit substantially from new developments such as integrating livestock and fish. Understanding the role of different household members in the production, marketing and consumption of both livestock and fish often reveals an important gender dimension. Understanding current roles, before the introduction of fish culture or its integration with livestock, may be important to targeting and orientating information so that women do benefit and are not disadvantaged. Where aquaculture is traditional in Southeast Asia, women in rural areas have important roles in feeding and marketing fish but modernization that has increased yields has totally changed livelihood systems (Box 7.F)

BOX 7.F

Access and benefits from aquaculture

- **Both gender and age in Hmong communities in Lao PDR affect access to, and benefits from, livestock of various types. Women and children have primary responsibility for small livestock and contribute to the general maintenance of larger animals, but men have most access to resources and benefits from livestock. Men were also the main proponents of introducing fish culture into the farming system (Oparaocha, 1997).**
- **In Than Tri district in Northern Viet Nam (Hoan, 1996) intensification of sewage-based aquaculture has had beneficial impacts women who now spend less time on laborious rice culture and more time marketing fish.**
- **Meat duck production favoured men more than women and children whereas the opposite was true for egg ducks in Northeast Thailand. Men usually consumed duck meat with alcohol, but duck eggs were a common lunch-time food for school children. The fish produced from the wastes was eaten by everyone in the family however (AASP, 1996).**
- **In female-headed households in Cambodia, which are relatively common because of war, aquaculture was more difficult to adopt because of a general labour shortage.**

Training and extension

Women have often been overlooked in training and extension. Men, usually the 'pond owner' in both Africa and Asia, have most contact with extension agents, who are also usually male. Men also usually have had more access to formal education and generally have greater mobility and access to information. This situation has been exacerbated by poor planning and management of aquaculture training, although alternative approaches have been found effective (Box 7.G).

Harrison *et al.* (1994) explains the lack of pond ownership by women in Africa 'is partly due to constraints in access to land and labour for pond construction and partly because in the past the technology has been promoted by men for men'. Assuming that knowledge will be transferred from the household member receiving training to others is clearly misguided. Women also have poorer access to credit that may be a key constraint to adoption of improved livestock and fish culture. Microcredit schemes may not provide money on the right basis for supporting aquaculture but has proved highly effective for encouraging women to intensify small livestock production. An extension focus towards women, has been particularly successful for poultry in Bangladesh and Ethiopia, and dairy goats in Ethiopia (Peacock, 1996) and targeting women is an important aspect in successful adoption of fish culture in Northeast Thailand (Little and Satapornvanit, 1996).

BOX 7.G

Training women in aquaculture

- **Residential aquaculture training at a distance from the village made participation impossible for women in an aquaculture development project in Eastern India (M. Felsing, pers. comm).**
- **Training women through participatory action learning around their own ponds in the village with flexible, short-term meetings with outside resource persons and early adopters has been successfully promoted by the Vietnamese Women's Union (Voeten, 1996).**
- **Women and girls were less involved in small-scale, backyard aquaculture in Bangldesh even though it often occurred within the homestead. An approach that focused on their needs, without excluding male family members, significantly increased their interest, knowledge and benefits from improved aquaculture based on culturally appropriate methods (Barman, 2000).**
- **A comparison of the effectiveness of videos to disseminate information about aquaculture found that women were more able to benefit from this medium than men in a project in Northeast Thailand (Little and Satapornvanit, 1996).**
- **Generally poorer literacy levels of women in South Asia excludes their access to aquaculture information to a greater extent than men.**

Targeting the young

Targeting schools with information about fish culture through school fish pond projects has become an essential part of most extension strategies in South and Southeast Asia as training people who are younger, more receptive to new ideas, and literate is believed to have the greatest developmental impact. The direct nutritional benefits of the fish produced by such students are a bonus. However, retention of this expertise in rural areas is an important constraint as the young are most prone to out-migration. In contrast, interest in aquaculture may be disproportionately skewed towards older family members who view the fish pond as a critical asset for supporting their subsistence needs in later life

Food security

In Bangladesh, small backyard ponds and ditches are critical to supply the small wild fish used for home consumption (Thilsted *et al.*, 1997). These resources are located within the household, allowing women full responsibility and control, and attempts to introduce more productive techniques will only be successful if women are

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fully involved. Indeed, aquaculture, as a relatively new activity, may even change intra-household relationships in favour of the weaker members. There may be a risk to household food security if commercially orientated aquaculture is promoted to men and larger, more valuable fish are produced and marketed (Barman, 2000).

Intra-household relationships

The involvement of women can be either encouraged or constrained by the nature of the social norms controlling power relations within households. It may affect attitudes towards intensification and integration. Inheritance practices and divorce proceedings tend to favour men in terms of retention of accumulated assets such as livestock and fish ponds. Control of resources used and generated by integrated aquaculture at the household level is often complex and the effective promotion of integrated livestock–fish requires the control of livestock and feed resources to be understood. Matrilineal societies in both Africa and Asia may share certain advantages with respect to females retaining or developing rights to fish production (Box 7.H).

BOX 7.H

Intra-household relationships affect production and consumption

- **Cash from fish sales is controlled by men, but tends to be used for household purposes in Zambia.**
- **Although fish farming is dominated by men in Malawi, production is limited in some households because women refuse permission to use maize bran as a pond input.**
- **Pregnant or lactating women are not allowed to consume muscovy ducks (Little *et al.*, 1992), geese and certain types of fish in Northeast Thailand.**
- **Consumption of raw and pickled fish with drink by men in Korea results in elevated levels of parasite infection compared to women.**

Sources: Harrison (1984), Dickson & Brooks (1997).

BOX 7.I

Summary of key points relating to the role of gender in aquaculture

- **The traditional role of men within the household normally means they are targeted with information and support for adopting integrated aquaculture. This may explain some of the poor success of attempts to promote aquaculture.**
- **Aquaculture is a non-traditional activity in many cases, and for this reason the opportunity for women to become involved in, and benefit from, aquaculture may be greater than other activities.**
- **Women and children frequently have responsibility for management of livestock, especially small livestock.**
- **Attempts to involve women, children and men in developing appropriate integrated practices requires analysis of how information can be disseminated and used within the household. The needs of women balancing reproductive roles, and childrens' education need to be considered in training and extension strategies.**
- **Power relationships within the household can affect who can participate and benefit from integrated livestock–fish.**
- **Involving women and children in integrated livestock–fish does not necessarily benefit them in the short or longer term.**

A developmental focus on certain types of livestock or fish can favour or disadvantage the individuals most at-risk within the household. The consumption of certain 'luxury' animal and fish products is often subject to belief and social controls (Box 7.H).

The establishment of farmer groups by gender may not be effective for extension if aquaculture requires agreement and contributions from both.

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Using inorganic fertilizers or dried chicken manure to grow back-yard vegetables. Aquaculture may compete for the use of these scarce resources

7A

Resource issues

7.4.1 INTRODUCTION

Closer integration between livestock and fish production can have impacts at the production or micro-level, the community level and on a macro-level that affects the regional or national economy. Promoting integration where the use of livestock waste is not traditional is often a key issue and related broadly to the level of evolution of the agricultural system (Chapter 2). How resources such as land, water, nutrients and labour are utilized to support livelihoods is related to their availability. Rapid development and population change can drastically change the 'resource balance sheet', requiring radical change in resource use.

Integrated livestock–fish can lead to competition for feed or waste use elsewhere in the farming system, and such changes to the traditional resource base, or its exploitation, can have negative effects. A major challenge is to explore how aquaculture, for fish is typically the 'new' component of the food production system, can be harmoniously integrated, improving the efficiency by which resources are used.

The effects of household and community access to feed resources is particularly important as fish can compete for use of key by-products. Modern production approaches can affect availability of feeds and waste. The consequences of consolidation of by-products, and livestock that consume them, are discussed in the light of impacts on the potential for integrated livestock–fish culture. The implications for resource use at the macro-level are discussed in 7.5.3.

7.4.2 MICRO-LEVEL

Using livestock waste where its use is non-traditional

Attitudes to the use of livestock waste vary greatly and are largely a function of the evolutionary stage of agriculture generally. Population pressure in particular has probably played a major role in leading to cultural acceptance of use of wastes (Edwards, 1992). If farming practices are based on extensive, crop-dominated production with low pressure on resources, it is unlikely that people will readily accept manure use in fish production.

A lack of interest in using manures in ponds sometimes also reflects the multipurpose nature of water bodies in which fish are stocked. Farmers usually refrain from manure use if water is also used for drinking or other domestic purposes. Some degree of eutrophication is tolerable if alternative water for drinking is available and water is used only for domestic cleaning. In northern Viet Nam a variety of factors limit the use of pig manure in fishponds, not least the need to use the water for washing and growing aquatic weeds as a feed for the pigs. The traditional shortage of nutrients for the staple crop, rice, has also meant that most pig and other manures are used on these crops. However, attempts to promote the use of livestock waste in small-holder aquaculture, where its use had

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BOX 7.1

Overcoming constraints to using livestock waste in Northeast Thailand

A cultural aversion to the use of manure in ponds had to be overcome before fertilization with manures and inorganic fertilizers was possible.

- **Extensive agricultural practices and low population densities mean that few livestock are raised intensively by rice farmers and the only manure used regularly is dried buffalo/cattle manure in rice nursery fields and small amounts of poultry manure in vegetable plots (AASP, 1996).**
- **'Green' water, in this seasonally water short area, is linked in peoples' minds to the occasional fetid water bodies in which a crop produced for its fibre, kenaf, is soaked to allow the soft organic matter to decompose ('retting'). Dead animals or pig manure are disposed of in surface water with similar results.**
- **Even farmers who understood the value of plankton as a fish food and the need for fertilization, were initially hesitant until an awareness of green water was promoted in a positive light, focusing on its 'cleanness' using a poster campaign.**
- **Increases of fish yields of up to 300 percent also convinced farming households of the benefits of fertilization and stocking larger seed (Edwards *et al.*, 1991).**

previously been minimal, have been successful once the underlying constraints have been understood (Box 7.J)

An analysis of the adoption and retention of methods to fertilize ponds disseminated among farmers to whom a simple buffalo manure plus urea message had been disseminated two years earlier found that farmers adapted their knowledge of the benefits of fertilization to the resources available (Turongruang *et al.*, 1994) Nearly half of the farmers continued to use various inputs to make 'green water' three years after they had participated in intensive farm trials. (Table 7.1). There were no dominant reasons given by the farmers who discontinued fertilization.

Subsequent attempts to encourage better-off farmers, who could afford to purchase them, to use increased levels of inorganic fertilizers to supplement limited amounts of on-farm manures, were also successful. All farmers in the trial used high quality monogastric manure even if they had to purchase off-farm, rather than the ruminant manure that they only had available on-farm (Table 7.2; Shrestha *et al.*, 1997)

Competition for feed and waste resources

Introduction of a new activity such as fish culture can increase the strain on the household, community or regional resource base. Alternatively the fish pond, through acting as a focus for recycling and use of manure, can be a stimulus to improved farming practices generally The availability of feeds and wastes can usually be related to the level of agricultural intensification, market structure and costs of alternatives.

TABLE **7.1**

Adoption of livestock wastes and other inputs in aquaculture in NE Thailand

Materials	Average amount (kg. pond^{-1} season^{-1})	Households (n=29)
Buffalo manure	890 5	4
Pig manure	908 0	7
Buffalo manure+urea	388 0+32.4	9
Pig manure +urea	45 0+189 0	1
Others +urea	900 0+9 0	1
Buffalo manure+pig manure	190.0+108.0	2
Buffalo manure+others	24.0+24 0	1
Buffalo manure+urea +others	15.0+1.5+240 0	1
Other i.e. duck manure, silkworm waste	101.0	3

Source Turongruang et al (1994)

TABLE 7.2

Livestock inventories and fertilizers used in an on-farm trial with farmers in Udorn Thani, Northeast Thailand

Farmer	Livestock owned			Livestock manure used (kg. pond.$^{-1}$ season.$^{-1}$)			Inorganic fertilizers used (kg.ha.$^{-1}$day.$^{-1}$)	
	Ruminant	chicken	pig	ruminant	chicken	pig	N	P
1	12	–	–	1200	360		3.5	3.2
2	-	100	–		650		10.4	5.1
3	4		10			96	3.3	1.1
4	3	320	–		448		3.1	1.4
5	-		7			120	2.1	1.2
6	-		2			180	2.9	1.6
7	-		-		50		6.5	1.8
8	7		-			1500	3.0	1.0
9	4		-			420	0.3	
10	1		3		150	200	5.9	3.9
11	5		-		1150		1.8	0.1
12	4	72			2760		4.1	2.3

Source: Shrestha *et al* (1997)

Competition for resources may be categorized into one of two types: Type 1, relating to feeds that were previously available for livestock; and Type 2 to manures and other byproducts of livestock production used as fertilizers or fuel (Figure 23). Examples of the first type are the introduction of rice bran as a supplementary feed for fish into a village situation in which it competes for its use as pig and poultry feed. Another is the collection and/or cultivation of grass to feed to either grass carp or ruminants

The diversion of livestock wastes for fish culture, rather than conventional crop production as an example of Type 2, could have major impacts on the wider farming system, particularly in nutrient-poor environments. Sustitution of inorganic fertilizers for manures, although achievable under short-term conditions, may be unsustainable in the long term, partly because of changes in soil structure and chemistry. On a practical level, inorganic fertilizers may be unavailable or expensive in many developing countries.

Overall agricultural and economic development inevitably cause changes in the relative efficiency or kind of resource use. Development of crop production, processing and marketing can totally change the availability of crop by-products for livestock and fish at the local level. Modern varieties, for example, in addition to producing more grain can also produce more by-products such as brans. Modern, high-yielding varieties of cereals are generally short-stemmed, reducing the amount of straw available for livestock feed and bedding.

Traditional uses of cereal bran

The layer of fibrous bran surrounding the starchy endosperm of the region's major cereal grains, rice, maize and wheat is a key resource for livestock and fish production. Rice bran in particular is critical to the production of monogastrics, especially pigs in Southeast Asia and dairy animals in South Asia. Its use as a supplementary feed for fish therefore conflicts with its current use. The amount of ricebran and other by-products (principally broken rice, husk and straw) available to the household depends on cropping intensity, area, yield and post-harvest disposal of by-products (Box 7.K). Improved

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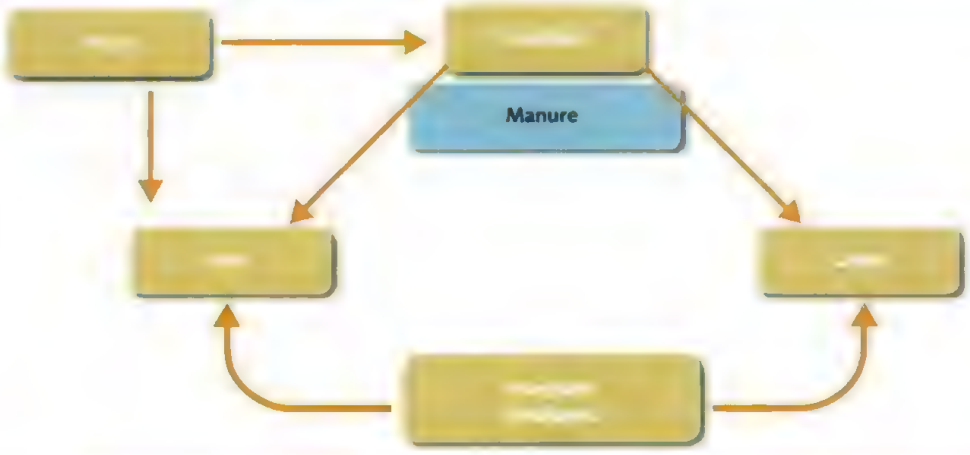
FIGURE 23

Schema showing main possible resource flows in conventional mixed farming and the alternative use of livestock wastes in fish production



BOX 7.K

Contrasting rice land holding, rice yield and pig production

Land holding and level of intensification affect both rice yield and availability of by-products:

- **in Northeast Thailand yields of around 1.7 tonnes paddy. ha^{-1} are normal in the single, annual rainfed crop. Riceland holdings of around 2 ha are the norm, producing 0.4 tonnes of rice bran year^{-1}, assuming paddy contains 12 percent rice bran. The rice miller keeps the rice by-products as a milling fee, and raises pigs which results in concentrations of pigs raised by fewer farmers and generally a much poorer efficiency in the reuse of wastes;**
- **in areas of the Red River Delta, Northern Viet Nam, yields of between 4-7 tonnes. ha^{-1} crop^{-1} are the norm. Two irrigated crops of rice produce only between 0.2 and 1 tonnes of rice bran as household rice holdings are small (2 000-3 000 m^2). Small holders in Northern Viet Nam still raise pigs and retain wastes for use on the farm.**

TABLE 7.3

Characteristics of pig production in three area

Characteristic	Cambodia/Lao PDR
Main feeds	Rice bran Cooked vegetables Waste human food
Production system	Scavenging Household
Current integration with fish	
Wastage of manure	+++
Rice milling	Hand milled in the household
Notes	In one household, an average of two hours daily labour was required to collect sufficient aquatic weeds to complement the 7-10 kg rice bran and 1 kg broken rice to fatten 4 pigs

+ - +++; low to high

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BOX 7.L

Hybrid maize enhances integrated approach

Growing hybrid maize can result in more bran as well as a higher grain yield. Whereas local varieties produce about 290 kg grain year^{-1}, hybrids can produce 660 kg year^{-1}. This means farmers need to plant only 0.4 ha maize to supply a 300 m^2 pond with adequate bran as opposed to 0.9 ha required if the bran derived from a local variety of maize.

Source: Noble (1996)

varieties and intensification can increase availability of bran considerably to benefit both fish and livestock production (Box 7.L).

Benefits for the maximum number of rural people probably relate to raising livestock at the household level with the wastes produced meeting both the needs for crop and fish production. Retention of rice bran by the rice-producing household is a prerequisite for pig production remaining a household level activity, although diversification of the diet to include other home-produced or purchased inputs is also important. Small-holder pig rearing was formerly common in Northeast Thailand but is now concentrated in the hands of local rice millers and agro-industry. In Northern Viet Nam where household-level pig rearing remains common, production of pigs is linked closely to local feed supplies and markets, whereas elsewhere the introduction of mechanical rice milling by entrepreneurs in the village appears to having stimulated consolidation and specialization of livestock production. In turn this limits access to manure for use elsewhere in the farming system. A comparison of ricebran use for pig production in three areas of Southeast Asia reveals the char-

of Southeast Asia

Area	
Northeast Thailand	**Northern Viet Nam**
Rice bran	Rice bran
Broken rice	Sweet potatoes
Concentrate	Potatoes
	Trash fish
	Concentrate
Penned	Penned
Mainly peri-urban or rural resource-rich e.g. rice millers	Household
+	+++
++	
Milled in village ricemill, rice by-products mainly retained by miller	Milled in village rice mill, rice by-products mainly purchased back by rice grower
Rice millers tend to waste much of their available pig waste. In one study only 12 percent of pig producers raised fish, but more than 50 percent gave the manure away and others sold it for fertilizing rice or vegetables	77 percent of households fatten pigs but only 10 percent of manure is used in the fish pond, 75 percent is used in the ricefields and the balance for vegetables (Dinh, 1997)

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BOX 7.M

Increasing the village pig herd in a village in Northeast Thailand-potential impacts on fish production

- **It was estimated from a feeding trial that a herd of around 50 fattening pigs could be supported in the Northeast Thai village of Thap Hai if the animals were raised on a traditional diet based on cooked rice bran, household scraps and aquatic vegetables. If rice by-products available in the village were reduced to only 14 percent of a total balanced diet that included dried cassava chips produced in the village and purchased concentrate, the number of animals fattened could be increased to over 400.**
- **If the wastes were used for fish culture, estimated yields of 1.0-11.2 tonnes over 6 months could be increased to over 12 tonnes in line with changes in both quantity and quality of wastes produced. These figures are based on total village level production but could be based on 100 households fattening 4 pigs each or 4 households raising 100 pigs each. The model, however, assumes continuous milling of rice through the year, which in an area of highly variable out-migration practice is unlikely.**

(Little and Satapornvanit 1997)

acteristics of current systems and opportunities and threats to adoption of integrated livestock-fish (Table 7.3)

More livestock – more waste

Increasing the feed resource available is a critical prerequisite to increase the carrying capacity of monogastric livestock and thus the wastes available for associated fish culture. Several ways exist to increase the amounts of livestock and fish that could be produced with the current levels of rice by-products. Mixing limited amounts of rice by-products with purchased concentrates, and/or more feeds raised on the farm e.g. cassava, maize, soybean, sugar cane, dramatically increase the number of livestock that can be raised in the village, manure produced and potential fish yields (Box 7.M). Inorganic fertilization of fish ponds, together with rice bran fed directly, or manure derived from rice-bran-fed livestock also increases fish yields dramatically. In a study of integrated farming in China, the densities of pigs produced were clearly supported by imports of rice by-products and concentrates into the area (Guo and Bradshaw, 1993)

Consequences of less manure

Diversion of livestock waste to fish production, rather than fertilization of terrestrial crops may threaten the sustainable output of staple crops. Even when inorganic fertilizers are available and used intensively, most farmers living in the Red River Delta, Viet Nam, believe that organic inputs are essential for maintaining yields. Household-level demand for manure is so strong in this area, that its relative value for fish culture must be compared to its use elsewhere in the farming system. Such is the farmers' understanding of their system that the balance of manure used is probably optimal. The key role of the pig is maintaining soil fertility in the face of declining fertility and soil acidification is a major concern (Patanothai and Yost, 1996). The possibility of more pig manure being used for fish culture as rice prices decline, or small-scale and household-level pig production by rice growers is replaced

BOX 7.N

Summary of key resource issues

- **Physical environments underlie the cultural value of livestock and fish.**
- **Changes in perceptions of fish culture and production of fish on livestock waste are possible.**
- **Changes in resource use stimulated by aquaculture could have negative impacts on overall livelihoods.**
- **Opportunities for resource use in aquaculture change in relation to the dynamics of the wider farming system.**

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A traditional rice mill in Cambodia. Prior to mechanical rice mills every household would mill its own rice and rice by-products were available for raising livestock

by large-scale production by entrepreneurs concentrated spatially in the more favoured locations, has important consequences for the sustainability of the wider farming system Implications for competition for concentrates are considered further in Chapter 8

Mixed farming systems have collapsed when the amount of nutrients from livestock has drastically declined. Although this "involution" has mainly been associated with vulnerable tropical highland areas with high population pressures, changes to the balance of livestock and soils are occurring elsewhere. Most mixed farming systems in the developing world have a negative nutrient balance (Steinfeld *et al.*, 1997) and any diversion of livestock wastes to fish culture must be carefully considered. The key advantages of fibre-rich ruminant manure to soil fertility is through improved capacity to retain nutrients (cation exchange capacity), hold water and maintain soil structure. Their value in fish ponds is much more limited (see Chapter 5), but under most conditions they are still the most widely available and used input. In Bangladesh, 88 percent of farmers used their own cattle dung as a pond input (Gupta *et al.*, 1998), in a country that uses ruminant manure for fuel and house building in addition to a field fertilizer.

In areas where agriculture is less intensive, such resource conflicts for manure and vegetation for feeding fish are less critical but may also be partly attributable to the low levels used. Indeed, the possibilities of increased use of pond water for vegetable production probably increases the availability of green fodders that could be used both for livestock and fish production

On a regional level there are implications for promoting aquaculture integrated with livestock or as a specialized activity, on the demand and price of feed grains, and the consequent economics of livestock production. The political economy of livestock development globally favours the growth of vertically integrated transnational agribusinesses producing and trading commodities, rather than improvements in local systems for local people. Export-led

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Electric and diesel powered ricemills have changed the availability and quality of rice by-products available to farmers in some areas of Asia

growth in agricultural commodities such as grains or after 'processing' into value-added livestock or fish ('seafood') products is vigorously promoted by many developing countries. Little attention has been focused on improving nutrient efficiency and reuse of wastes by such organizations, except where regulatory authorities, mainly in developed countries have enforced it (Steinfeld et al., 1997). Typically the solutions have been capital intensive and 'high tech' in approach but it should be remembered that resource-poor people who compete to extract and use them often add value to wastes in developing countries.

7.4.4 BENEFITS

Diversified production of both livestock and fish can lower risk and improve returns on land, labour and investment. Although several studies have shown that better-off households tend to have more livestock and are more likely to be fish producers (Edwards *et al.*, 1983; Ahmed *et al.*, 1993), integration can also benefit a range of other people. Benefits from livestock–fish integration can be viewed from different levels principally those of producers, intermediaries and consumers.

Where aquaculture is well-established and commercialized, consumers benefit from greater choice and lower prices. This has clearly been the case for urban, poorer people in Southeast Asia where the development of polycultures dominated by tilapia raised on feedlot livestock waste, have led to fish remaining affordable over the last two decades. A survey in South Viet Nam indicated that whereas richer people eat wild, mainly carnivorous fish, cheaper and cultured tilapias were favoured by the poorest (AIT/CAF, 1997). In most of Africa, where production is a long way from being sufficiently high to drive prices down and cultured fish are more expensive than alternative sources, the urban poor have yet to benefit in this way from aquaculture (Harrison *et al.*, 1994).

Poorer people in Asia often become involved in supply and distribution networks that develop around integrated production systems. Supplying inputs such as fish seed and trading wastes and by-products are employment niches that poor people quickly occupy.

Benefits to food security may be relatively more important for household producers who are 'less successful' at aquaculture, producing less fish but tending to eat rather than sell them. Rural aquaculture of this type has an important role to play in national food security as it may be the only way that fish can be produced in scattered rural communities with poor infrastructure that cannot be served by conventional market methods.

It has long been appreciated that livestock are a means to reduce, or spread, risk for farmers (Orskov and Viglizzo, 1994). Risk aversion may also be an important rationale for small-holder farmers to diversify and integrate fish production (Ruddle, 1996).

However, diversification primarily to increase income may be more common. Fish are generally more like small than large livestock in terms of their characteristics affecting risk (Table 7.4). They are generally more marketable locally and

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easier to add value post-harvest. The ability of smallholders, especially those used to seasonal abundance of fish, to deal with sudden mortalities and emergency harvest of fish, is typically much greater than for disposal of livestock. Fish also have lower individual maintenance, feeding requirements which allows strategic use of scarce resources in contrast to large livestock.

Integration with fish production may reduce the risk to livestock production, or the overall farming system on mixed farms in the tropics, in several ways. Although fish are more sensitive to shortages of water than livestock, their production may enhance and conserve water availability both for livestock directly and their feed production. Improved stability of water availability is a major means for reduction of risk since fishponds often become a focus for diversification. Maintaining fodder quantity and quality for livestock is an example of how pond culture can reduce risks associated with ruminant production. Fish culture is more risky than livestock production in some respects. Observing and assessing the growth and survival of fish and monitoring theft tends to be more difficult than for livestock, for example. However, theft of fish requires specialist gear and skills and is probably more difficult than stealing small livestock. The physical integration of livestock and fish may reduce the costs of providing security from loss of many types however.

How farmers adopt fish culture as part of their farming system is also closely linked to their avoidance of risk. The perception of aquaculture as being a high risk activity may lead to selection of an unsuitable site for pond construction, rather than an optimal site currently used to produce a tried and trusted crop. Farmers may resist production of livestock near or close to fishponds if the pond is located away from the homestead. Their conservative behaviour is often explained by the greater likelihood of theft, of both livestock and fish, in such situations. Rice farmers living on floodplains where wild fish are still seasonally abundant, may only stock fish in years of low flood when both wild fish supplies are low (Gregory and Guttman, 1996) and the likelihood of cultured fish loss through flood is least.

Large rice mills concentrate food resources such as bran in Battambang, Cambodia. This supports commercial livestock production but may undermine household level systems

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TABLE 7.4

Factors that reduce smallholders' risk through production of livestock, fish or both

Factor	Small livestock	Large livestock	Fish	Does integration reduce risk for either livestock, fish or both ?
1. Feeding level required to maintain value	++	+++	+	Possibly, if 7 is important. Irrigation to maintain feed availability for livestock Integration with livestock ensures that fish are fed consistently
2. Sensitivity to lack of water	+	++	+++	Water for fish can reduce water shortages for livestock
3. Local marketability	++	+	+++	Local markets are more likely to be oversupplied and alternative products are advantageous
4. Easy to estimate asset value	++	+++	+	If livestock are penned for more efficient integration, their asset value may be more apparent
5. Provide collectable nutrients for other on-farm production	+	+++	+	Use of livestock wastes for fish may reduce nutrient use elsewhere, increasing risk
6. Water available to produce other crops			+++	See 2
7. Opportunities for value-adding post harvest	++	+	+++	
8. Ease of theft	+	+	+++	
9. Ability to monitor theft	++	+++	+	As above

+ - +++: low to high

Overstocking is common practice, both in terrestrial pasture management and subsistence aquaculture, and may derive from farmers' attempts to reduce their risk. More, if less productive, individual livestock or fish may be a strategy to counter risks of loss and improve opportunities for marketing in resource-poor, unpredictable environments

7.4.6 LABOUR

Labour is often the most abundant resource available on small-scale farms in Asia and under-employment is a typical feature of the rural economy. The promotion of aquaculture to provide employment opportunities is often advocated but labour requirements are often poorly understood. Furthermore, other activities may be more appropriate to resource-poor peoples needs. Conventional analysis of labour inputs into agricultural activities has looked at returns to labour for different components. In such analyses, however, the labour inputs of women and children have been undervalued and the complexity of integration may obscure conflicts and complementarities

The importance of off-farm employment options has also often been ignored, despite the fact that if such opportunities increase in rural areas, households adapt and food production quickly becomes only one part of an overall livelihood strategy. How resource-poor people at the household level use their labour to minimise risks and optimise gains is critical in understanding the potential and constraints to integrated livestock–fish. In reality much food production results from part-time farming, the characteristics of which are fashioned as much from the type of off-farm employment opportunities as the physical and social cultural environment. The nature of household-level, integrated livetsock/fish will depend on the

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Comments
Fish are cool blooded and lose condition more slowly than underfed livestock
Small units of food can generally be sold more easily
Often difficult for inexperienced fish farmers to estimate amount of fish in their pond
Most important where nutrients are most expensive or least available
The pond as an on-farm reservoir is a very important advantage in water-short situations
Sudden loss of livestock or fish may mean total loss but home processing of fish products is relatively simple and the techniques may be well known because of seasonal surpluses of natural fish
If livestock and fish are raised close to one another guarding is more likely and risk of theft reduced
Similar to (4)

relationship between fish and non-fish farm components, access to the resource base and modern technology and will be related to opportunities for non-farm employment.

A common phenomenon related by many to declining opportunities for integrated livestock–fish is the off-farm migration of household members. Less available on-farm labour usually results in modifications to farming practices but may also result in benefits. The compatibility of labour demands for fish culture compared to livestock, other farm activities and off-farm employment of various types is critical as outlined below.

Integration to absorb labour

Returns to labour in a tri-commodity on-campus, integrated farm (livestock–fish/vegetable) were highly favourable for fish, favourable for pigs and vegetables but less so for egg ducks (Edwards *et al.*, 1986). The complexity of managing the enterprises at a commercial level on a single household basis probably explains the uneven performance and why such systems are rare. A major finding was that the multi-component 4000 m^2 farm absorbed only 34 percent of the available family labour despite the relatively high inputs required for vegetable production. The relatively low extra labour requirement for fish culture within livestock operations probably explains much of their appeal. It also explains why livestock and fish are compatible livelihood options in peri-urban areas where off-farm employment options are more varied and flexible. Ruddle and Zhong (1988) also found a high level of underemployment in the Zhujiang Delta, China, at the time when management of the dike/pond systems were at their most labour intensive. At this time less than half of household income was derived from the dike-pond system and 'surplus' time available for other, often off-farm employment varied from 16-70 percent of the household labour budget. The compatibility of labour requirements for different components of the dike/pond system have age, gender and seasonal aspects (Figure 24). The rapid industrialization of the region, however, is contributing to a breakdown of the system as labour-intensive sericulture, traditionally managed by young women, has become uncompetitive with factory employment and opportunity costs of land and water have increased. Aquaculture has become more intensive, relying even more on external inputs as such costs have risen.

Migration

Migration for work can mean long periods away from the farm or short-term or seasonal absences. Household members drawn away from agriculture may be men, women, the young or middle-aged Migration from the farm does not necessarily mean less potential for aquaculture as it can result in greater household capacity to invest in agriculture. However, balancing on-farm activities such as aquaculture with off farm employment tends to be easier if employment is local.

Options for off-farm employment often change in tandem with a broader dynamism; traditional patterns of labour based on

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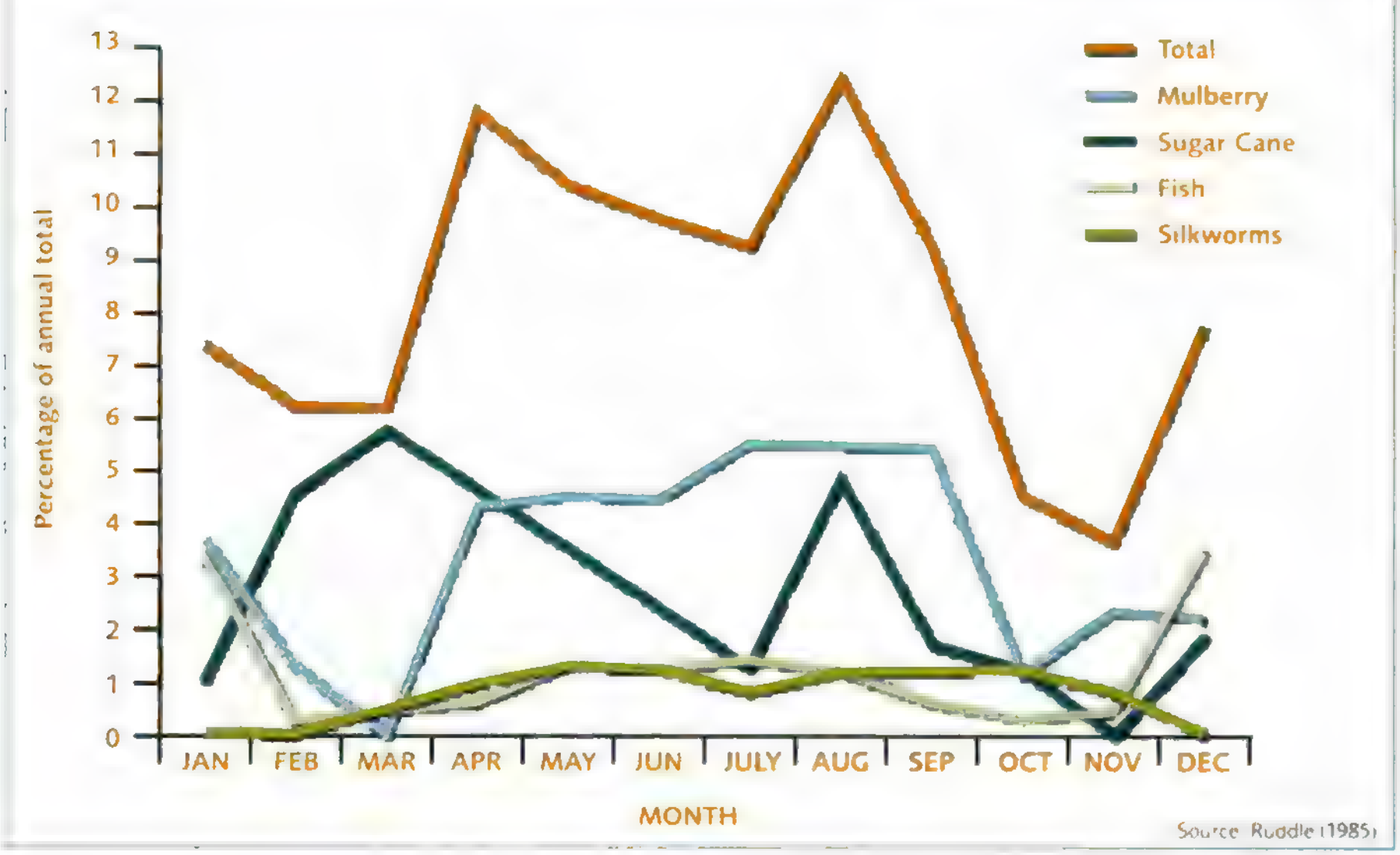
Annual Distribution by Crop of Labor Input to the Dike-Pond System of the Zhujiang Delta, China (percent of Man-day Month^{-1}Crop^{-1})



Source Ruddle (1985)

reciprocity, the roles of old and young, male and female, and the proportions of household and employed labour use may all be under pressure or already changed in response to new opportunities. Less labour is required as pond construction and then fish harvest have become more mechanized. Feeds for livestock and fish may be produced industrially, rather than on-farm. Alternatively, labour shortages through migration or other causes may undermine the productivity of, or interest in, aquaculture as it suffers from the labour crunch. If aquaculture, in common with other components of the farming system, is marginal in terms of meeting the household's needs, it is likely to be abandoned or extensified

Integrated aquaculture as a transitory livelihood option

Although increasing opportunity costs may eventually result in small-holder, semi-intensive aquaculture integrated with livestock becoming less competitive in certain situations, it is likely to be an important developmental option for the foreseeable future in many developing countries. Similarly, rice/fish production has been adopted as a low risk entry point for farmers to diversify their farming systems in certain parts of Asia, partly because fish culture is less labour intensive than other options. Integrated rice/fish culture, however, requires significantly more labour than rice alone and this factor has been one of the main driving forces for farmers to switch from ricefield to pond culture of fish in Northeast Thailand (Little *et al.*, 1996)

In one example of successful commercial egg chicken/fish system (Engle and Skladany, 1992), the scale of operation meant that household labour alone was sufficient and the income produced at a level that inhibited off-farm migration. Moreover the labour

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requirements of the chicken and fish components were considered highly favourably compared to the far more onerous on- or off-farm alternatives e.g. field cropping or construction work. This situation can change rapidly when market access improves, land values increase and off-farm opportunities become more attractive, especially for younger people. Expectations of younger members of the family are higher, especially if they have more formal education, and can often only be met from truly commercial level enterprises.

The likelihood of aquaculture integrated with livestock becoming, or remaining, an attractive option will be greatly affected by the cost of labour that in turn is linked to the wider economy As rural economies change from a subsistence focus, the proportion of landless and resource-poor often grows. As this group typically has few options in the formal economy, their employment in the sectors such as aquaculture and livestock can become crucial to their livelihoods. The contracting out of fish harvest, trading of seed and the removal and trading of wastes often become the preserve of such resource-poor people.

Increasing median age and declining household size are good indicators of changing need and interest in intensification of aquaculture with livestock. Lovshin *et al.* (2000) evaluating retention of integrated livestock–fish in Guatemala a decade after its promotion found reduced interest in aquaculture, partly as children had left home and remitted urban wages to support older family members left on the farm Under these conditions there was less need for increasing fish yields and less labour to do so. In contrast, the integration of horticulture and livestock around small, deep ponds is particularly popular with older people in Northeast Thailand as a method to save time and labour. They manage their ponds to meet their daily need for vegetables, herbs and spices rather than optimising fish or any other single product. Such people identify the convenience, and the reduced time and effort spent gathering such products from a dwindling natural resource base, as major incentives.

Promotion of integrated livestock–fish

Promoting the integration of livestock–fish requires a clear framework to identify major factors of importance, to clarify thought to direct action and to aid in communication between the various stakeholders.

Clarification of purpose is a critical first step in promoting integrated livestock–fish. Is the major objective to improve the livelihood of the landless poor through employment and consumption-related benefits, to stimulate agricultural labourers to integrate subsistence-level fish culture within their home plot, or to support commercial farmers capable of producing large amounts of fish for sale locally at affordable prices? An important priority is to identify the major beneficiaries of any promotion and clarify stakeholders that could be impacted by development. If substantive changes to both livestock and fish components are required, clearly the complexity is increased. The need for interdisciplinarity, action at multiple levels (household, local, regional) and with a range of partners (farmers, agribusiness, extension agents) makes the task more difficult.

Typically, attempts to promote integrated farming have been made by technical scientists, often working within a narrow disciplinary mode Failure to assess if promoting livestock and fish, either as single activities or integrated, is appropriate to meet the farmers' needs and resources is common. Alternatively, grass roots organizations often recognise the need for, but fail to understand, the technical issues and constraints. Although current technologies can be improved, major impacts could be made if existing knowledge were promoted to people with appropriate needs and resources. Limited capacity to assimilate technology is a major constraint to development in general (Juma and Sagoff, 1992).

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Participatory research with small numbers of resource-poor farmers in Northeast Thailand led to recommendations that could be promoted to a large group throughout the region. This necessitated producing stand-alone extension materials that could be disseminated by the Department of Fisheries through a variety of agencies present at the local level

7.7.2 DEVELOPING CAPACITY

A wide range of factors must be considered if livestock–fish integration is to fulfil its potential. Improved policy, infrastructure and institutions at national, and local levels are required, particularly if poor peoples' livelihoods are to benefit. Where success has occurred on a local basis, it is usually resource-richer individuals who have benefited from any research and development, and a generally supportive commercial environment that has sustained the practice.

The complexity and limited resources contributing to poor peoples' livelihoods makes developing and promoting useful information to them particularly difficult. Facilitators with experience in practical livestock, aquaculture, and often community development are required to work together if integrated livestock–fish is to be more widely adoptable by small-scale farmers.

7.7.3 SYSTEMS

The use of a farming systems research and extension (FSR & E) approach to promote aquaculture lags behind its use in agricultural development by at least a decade. Such an approach is essential if linkages between livestock and fish production are to be strengthened.

There are three major sequential steps of research leading towards the development and dissemination of information useful for farmers. A situation analysis should be made initially that assesses the needs and resources for change in the target group, but which also includes identification and understanding of the impacts of this change on other stakeholders. Some form of institutional analysis is also important at this stage since sustainable development is rarely brought about by a one-off event and the constraints as well as potentials of responsible institutions need to be understood. Identification and refinement of appropriate technologies and management through on-station and on-farm trials is the second stage that should be integrated with testing and dissemination of the information. This third stage, developing methods to disseminate information rapidly to large numbers of farmers, needs invariably to consider the complexity of the message, the nature of the audience and constraints of existing extension channels. Early identification of a recommendation domain, a targeted area or beneficiaries with relatively uniform characteristics, and an iterative process relating development of the technology with methods to disseminate it, are required.

The roles of the farmers themselves in the research and development process have been the

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focus of a major shift over the last two decades. A technology driven, "top-down" approach has been seen to fail especially for resource-poor farmers in marginal environments (Chambers *et al.*, 1989). The need for participation of the beneficiaries in setting the development agenda and involvement in the research process has become widely accepted. The need to integrate farmers' traditional or indigenous knowledge has been recognized. Focus on ecological agriculture and low external-input systems have also been recommended (Altieri and Anderson, 1986; Reijntjes *et al.*, 1992). The need for a balanced view on research approach in which outsiders, depending on the context and existing knowledge base, complement the farmers' skills has been proposed (Biggs, 1995; FAO, 1997a)

7.5.5 CONVENTIONAL APPROACHES

The success of intensive livestock systems is testament to how the 'transfer of technology' has worked for both producers of livestock and the feed companies that support them. In regions of high agriculture potential in both developed and developing countries, 'Green Revolution' techniques have resulted in quantities of feed grains sufficient to support modern-day intensive livestock production. Well-tested information has been extended through conventional or upgraded extension services to usually better-off farmers in well-endowed and relatively standard agroecological areas, latterly as the Training and Visit system (T&V).

The agribusiness concerns that control commercial feed grain and livestock production have used similar approaches to deliver efficient, vertically integrated production methods across a huge range of different locations. Broiler chickens are produced in places where agro-climatic and cultural conditions are highly variable. This approach requires huge resources often not available to governments, and has brought benefits mainly to more literate, better-resourced farmers in favoured locations.

The promotion of aquaculture as an option to recycle waste, or just to profitably utilise the borrow pits produced during construction of livestock pens, has often been relatively straightforward. Much of the livestock–fish production in Asia is of this nature and it has often developed with relatively little promotion by government agencies.

Such 'top-down', transfer of technology strategies have been less successful for extension to more resource-poor, complex and diverse situations. Agricultural extension services or agribusiness companies in developing countries have often focused on 'progressive' or 'advanced farmers', often as contact or model farmers, leaving poorer people untouched by such services (Box 7.0).

Some improvements have been made that have encouraged greater situation analysis and farmer participation, such as the 'Trickle Down System' (TDS) promoted in Bangladesh and Viet Nam (FAO, 1999). TDS is based on a reorganization of the conventional extension

BOX 7.0

Development of livestock–fish systems in Asia

- **Poultry-fish systems (longyam) were introduced into land-limited Java in the early 1980s and have spread largely through informal mechanisms (organic spread) rather than any formal extension service[1].**
- **In Central and Eastern Provinces of Thailand, commercial livestock–fish has developed to the extent that it is a dominant method to produce herbivorous fish and monogastric livestock. A wide range of variations now exist, largely as a result of farmer experimentation and adaptation of a basic concept to their own resource constraints of labour, land, water, capital and market.**
- **Although livestock–fish systems are less common in the Philippines than Thailand, raising fish with poultry in particular was still relatively common in a recent survey among commercial tilapia farmers in Luzon[2].**

Source [1]Kusumawardhani *et al.* (1994), [2]Molnar *et al.* (1996)

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Materials that farmers could use to collect poultry waste were developed with them and all extension materials tested with farmers to ensure comprehension

service based on training demonstration farmers and their subsequent training of fellow fish farmers. However, the basic problem remains: effective transfer of information to poorer people is most difficult. Rather than trickle down, 'trickle across' typically occurs, as farmers with more and similar resource levels benefit most from such farmer to farmer contact, leaving the basic problem of more widespread involvement of the poor unresolved. Lewis (1997) notes that despite a raise awareness of the need for partipatory approaches by international research organizations and their national counterparts, more rhetoric than change has occurred. The superiority of formal scientific approaches and a top-down approach remain entrenched attitudes, while interest and understanding in social and equity issues remain a low priority

Another fundamental constraint is the limited capacity of most extension services and their fragmentation into specialist livestock and fisheries units with few links to broader agricultural extension. Typically their staff have limited knowledge of production systems more appropriate for the poor, have little training in extension methods and practices and are underfunded and poorly motivated.

Alternative roles for traditional extension agents to act as facilitators and promoters to a range of 'change agents' have been proposed (Scoones *et al.*, 1994; Edwards, 1997). Depending on the complexity of the technology and the degree of on-farm testing required, a minimalist approach may work well in which concepts and alternative approaches to farm production are presented rather than prescribed packages of tested technologies. Technological packages may just be too expensive for agricultural services to develop and provide in view of the diversity of possible recommendation domains (Byerlee, 1987) and their value too limited in terms of lifetime.

The role of extension worker as a diagnostician and advisor on available techniques that can support to both livestock and fish production suggests that changes in professional training and management are

required (Chambers and Jigginss, 1987). The training of livestock and other rural development and extension staff in basic fish culture and aquatic resource management techniques would be highly desirable. The potential training demand for this to occur would be high Brummett (1994) explains the advantages of vocational training delivered locally for field extension staff. Given the magnitude and urgency of the job, a central role for distance education for professional-level will be necessary and would potentially meet these needs at minimum cost.

Developing capacity for promoting both livestock and fish by the same professionals is a challenge. Castillo *et al.* (1992) promoting integrated aquaculture among small-holders in Guatemala found that, although benefits were greater among farmers raising livestock with fish, greater technical maturity and support was required from extension staff in its promotion. However, the integration of a fish production component within farms where livestock are raised traditionally can benefit the development of both components. Although indigenous knowledge of natural stocks is often extensive among rural people dependent on fish, this usually does not extend to culture because aquaculture is new or relatively recent. In contrast, husbandry of livestock, and management of the resource base, are often traditional. An approach that values farmers' knowledge but complements it with 'outside' knowledge will allow people to learn about fish culture through their experience with livestock; and concepts introduced with fish can, in turn, educate their views on livestock production. The need to make changes to long-established, livestock management practices because fish culture, as a new component in the farming system, requires it, can act to stimulate positive change of the traditional system. Introduction of improved waste management primarily to ensure adequate inputs for fish production can also improve the health status of livestock

Traditional livestock management concepts such as nursing and fattening can be useful in improving management of fish. In Lao PDR, a livestock extension network has evolved to support farmers' efforts in raising fish (Innes-Taylor, Unpub). The cold chain developed to deliver livestock vaccines is also used to disseminate hormones for farmers to breed their own fish and assure local fish seed supply

In practice adoption of fish culture through farmer-to-farmer extension can be stimulated through a range of change agents and the approaches and motives to improve fish, livestock or crop production interact. Surintaraseree and Little (1998) found that rice/fish farming spread in Northeast Thailand in this way, and that farmers' holistic view of their system meant that benefits occurred directly and indirectly through livestock, crop and fish components of their system

In the same region, written information on simple technical interventions involving the use of livestock waste and inorganic fertilizers in fish culture has been taken up by up to 55 percent of farmers receiving materials (Turongruang *et al.*, 1994). Moreover, as this approach did not require contact with an extension agent, information could be delivered through non-specialist channels at low cost. The private sector can also participate in this process. Commercial media disseminate information as attractively packaged technical articles on television and printed form in many countries. Institutional structures are often a barrier to this type of innovation and even when a more farmer-first approach is accepted, implementation can be slow or ineffective. The specialized education that professionals receive has been identified as one reason (Chambers, 1993) but the cultural norms of institutions and the wider culture typically accentuate the conservative view. Narrow outlooks on production systems also require broadening to encompass the wider resource system and an understanding of rural peoples' livelihoods (Edwards, 1997; Carney, 1998). (Box 7.R) Decentralized and more pro-active institutions are required if progress is to be made in improving access to relevant information by poor people

Problems in the promotion of aquaculture or the integration of livestock with aquaculture are not unique and need to be put in perspective with success in other fields of rural development. Harrison (1994) noted that 'the legacy of previous

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BOX 7.1

Development of integrated livestock–fish production in the provinces around Bangkok, Thailand

- Aquaculture is not traditional in Thailand. Peoples' appetite for fish to complement a diet of rice and vegetables was met through capture of wild fish and a host of other aquatic animals until relatively recently. Chinese immigrants introduced aquaculture, of common carp, and Chinese carps, in the early 20th century although cultivation of native fish e.g. Pangasius hypothlalmus, *Oxyeleotris marmoratus* and *Trichogaster pectoralis*, on a small-scale may pre-date this practice (Edwards *et al.*, 1983). It was only with the decline of the wild fish harvest and as techniques for the controlled breeding of these species became known that their culture became more widespread. In the 1930s attempts to popularize the culture of *Trichogaster*, failed. Culture of tilapias in ricefields and ponds was promoted in the 1950s, and people were encouraged to raise fish together with pigs and poultry. One pamphlet describing how to culture tilapia sold over 300 000 copies in two editions at the time (Edwards *et al.*, 1983). Irrigation projects were also beginning to have a major effect on the availability of natural fish stocks in the Chaophraya basin that dominated Central Thailand, especially after the completion of the Chainat Dam and distribution system in the early 1960s.
- In the first detailed survey of its type, it was found that aquaculture, in a variety of forms, was practiced by around 3 percent of farms in one central province, Pathum Thani by the early 1980s. Integrating livestock, especially pigs but also chickens and ducks with fish culture had become established in the early 1980s; most practitioners began five years prior to the survey. Longer established operations were concentrated around the central provincial city. Farmers continuing to produce rice and raise fish as a minor crop were much less likely to integrate livestock with fish. Farms raising fish for between 10-30 years were more often diversified and operated by farmers of Chinese descent.
- During the 1990s, as Thailand's industrialization accelerated, the centre of integrated farming has moved outwards from Bangkok as land values have soared and factories and residential areas have developed. Integrated livestock–fish has grown rapidly in response to market demand generated by urbanization and rising purchasing power. Initially beneficiaries were more urbanized people, closest to information, inputs and markets but recent trends indicate the entry of rice farmers into aquaculture, after conversion of rice fields into shallow ponds. Pig and chicken manure is purchased or removed free from nearby intensive operations and often transported by middlemen. In these livestock-dense areas of Central Thailand, livestock farming at the scale required needs high investment, but pond culture of fish has much lower capital costs, especially as the cost of mechanically constructed ponds has steadily declined. Improved market access and road infrastructure has also reduced the entry costs, opening fish culture as an option for a wider range of farmers. Knowledge about raising livestock and fish together has been disseminated in the media and through vocational training. Credit, often from Government agricultural banks, is now also more widely available.

development interventions has a profound influence on the way that rural people respond to new ones' with regard to adoption of aquaculture in Africa. Many of the problems that have beset extension of aquaculture and its impact in rural communities, be they poor rates of adoption or 'low' output, are common to 'top-down' development initiatives in other sectors.

7.5.7 EXTERNAL FACTORS

The adoption of integrated livestock–fish has been uneven throughout the developing world, even in places with suitable agro-ecological conditions. Sustained periods of warm temperatures are required for the most efficient treatment of organic wastes but in practice successful integration occurs across a wider range of environments. Where the practice has become established, and is today most significant, overall economic and infrastructural development have been more important than formal extension. A historical dependence on fish is far more important than any tradition of aquaculture as the rapid adoption in Thailand has shown. In certain areas e.g. West Java and

BOX 7.Q

"Top down" small-scale duck-fish integration fails

- **Farmers who adopted, and benefited from, integrated livestock–fish in Pathum Thani by the early 1980s were a small rural elite with significant resources. The relative poverty of the majority of farmers growing rice in the same Province stimulated the concept of scaling-down livestock–fish farming to meet the needs and resources of ordinary rice farmers. Rice farmers, especially those with poorly diversified farming systems, were more likely to seek off-farm employment, and consumed significantly less fish than average. The rationale of introducing livestock–fish systems was to improve both household nutrition and income. Both on-station and on-farm trials were run to develop a technical model that could be managed and sustained by resource-poor farmers. Farming households were actively involved, participating in pond construction and provision of a proportion of the livestock feed. The researcher-managed trials followed a structured design that farmers followed, and there was little flexibility or involvement in decision-making. Egg-laying ducks were chosen as a suitable type of livestock, as a preliminary assessment had found duck eggs to be readily marketable in the village and their integration with fish culture technically feasible using locally available materials. A standard design of pen that kept the ducks enclosed over the pond water at all times ensured that all the manure and spilt feed entered the pond. If ducks are allowed to scavenge for a portion of their own feed, pond dikes quickly become eroded, and much of the waste lost. On-station research found that 30 ducks kept in this way over a 200 m2 earthen pond stocked with Nile tilapia for 6 months produced enough fish to meet all the estimated animal protein requirements of a family of five.**
- **Unfortunately, once support for the purchase of livestock feed was withdrawn, the farmers were unable to sustain the system. The ration given to the high-yielding ducks had to be purchased as the farmers' own paddy rice was unsuitable for inclusion in the balanced diet required to maintain egg-laying rates at economic levels. Most families found managing the high level of inputs and outputs difficult. A regular cash outlay for feed was required and the large numbers of eggs produced daily were difficult to market. The relatively large amounts of fish produced were greatly valued but the system did not fit within the farmers' overall resource base, with cash and time being particularly limiting.**

BOX 7.R

An approach to understanding constraints to fish production in rain-fed cascade tanks systems in the Dry Zone of Sri Lanka

- The ancient hydraulic civilization located in the dry zone of Northwest Sri Lanka was based on 'tank' irrigation. The storage of rain-water in 'tanks', large, man-made reservoirs, within watersheds that could be used to irrigate the crop of rice was critical to reducing vulnerability to shortages of water and also provided an important source of fish. In the last century these systems have been rehabilitated and watersheds have become more densely populated. The pressure on the resource base has intensified, especially as the water held in these community-managed tanks is used for a variety of purposes. Most households rely on them for domestic water supply, and in the dry season they become an important grazing and water resource for livestock in addition to their primary purpose to supply irrigation water for the rice.
- The tanks, arranged as a complex mosaic within watersheds, interact in terms of movement of both water and fish through the seasons. As the rains begin and the upper watershed tanks fill, they begin to overflow into the catchment of the tanks below. This allows upward migration of aquatic animals to repopulate upper tanks that may completely dry out during the dry season.
- Understanding how individuals from communities gain access to, and benefit from, these aquatic resources is complex. Their intensified management is a challenge. The nutrient links between management of grazing livestock and fish are clearly important and a major determinant of overall productivity.

Working with communities surrounding different tanks in the same cascade to improve livelihoods requires an interdisciplinary approach to understand and resolve potential conflicts. A stakeholder approach that builds on an understanding of the resource base and the interactions between the various components is a useful way to realise the potential of these systems for equitable development.

the Philippines, high land costs and a relative abundance of large water bodies appears to favour the development of cage-based operations but pond-based fish culture has also continued to develop, particularly in West Java with fewer problems of land tenure for small-holders than the Philippines.

In countries where economic conditions are suitable and an entrepreneurial class has access to land and water, integrated livestock–fish can spread with relatively little formal support, at least among better-off farmers. Technology transfer by agribusiness has been effective in the transfer of modern intensive livestock systems, and if other resources and market opportunities are suitable, entrepreneurs have quickly used the waste for aquaculture and/or horticulture (Box 7.P). Where integrated practices have become established such as in Thailand, the media and agribusiness have supported information flow and wider economic development has stimulated intensification of livestock production.

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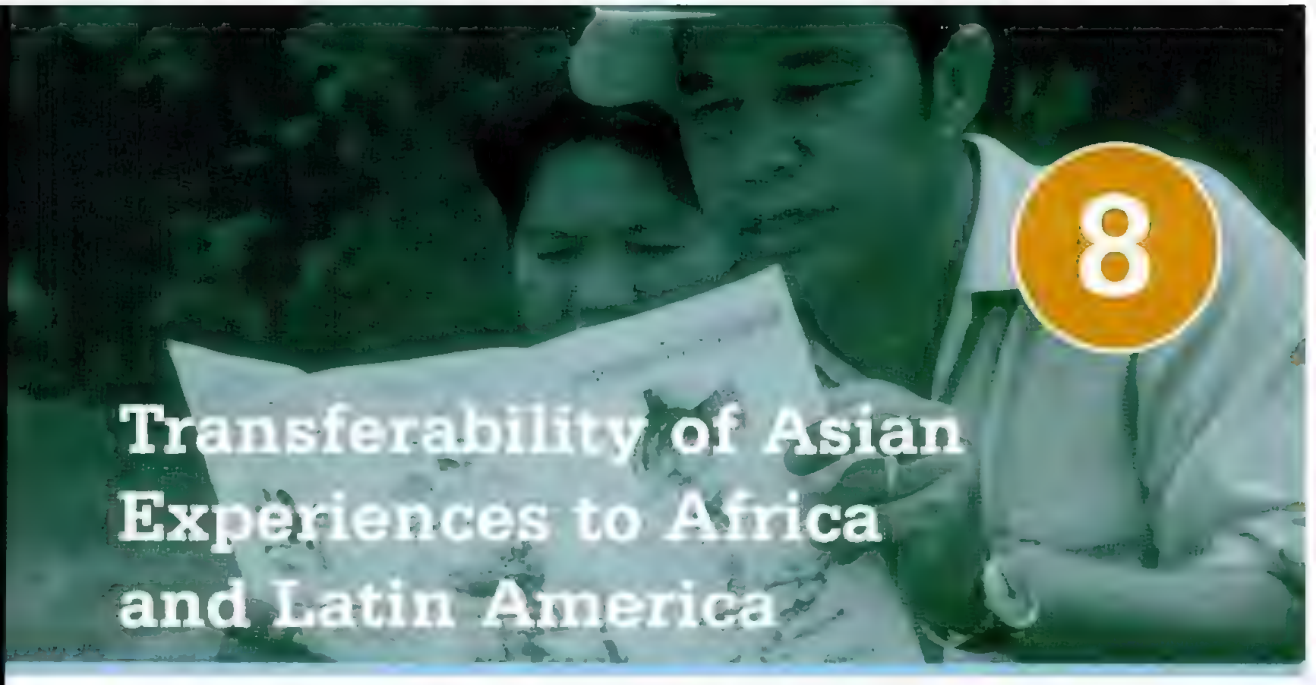

8 Transferability of Asian Experiences to Africa and Latin America

The widespread belief that rural aquaculture has been proven to be more appropriate in Asia than either Africa or Latin America is reviewed. A range of shared constraints to adoption of aquaculture has been identified, especially when integrated with livestock, using evidence drawn from evaluations of development projects on the three continents. We firstly consider the general status of aquaculture development and identify common features, before considering information needs for successful adoption of rural aquaculture and the institutional constraints to their development and delivery.

Solving the problems of poor fish seed supply and losses through theft and predation are as fundamental to successful adoption of aquaculture by small-holders in Asia as well as Africa and Latin America. The role of cultured fish in meeting the needs of rural people is compared, and many similarities identified, especially the reliance of fish pond water to diversify and stabilise surrounding farming systems. Benefits from aquaculture within the household and to non-producers are also interpreted from developments outside Asia. Attempts to promote aquaculture on a community-level basis have been made in many developing countries and post-project evaluations of several projects allow some broad conclusions to be drawn.

A summary of some key factors that explains the apparent dichotomy in integrated livestock /fish development among small-holders in Africa, Asia and Latin America concludes the section.

8.1 General considerations

The broad developmental challenge in both Africa and Latin America is similar to that in Asia: populations are rapidly increasing and

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environments, and thus the means to support increased numbers of people, are degrading. Although both mean population densities and absolute numbers of poor people are lower in Africa and Latin America than in Asia, acute poverty and highly inequitable development is common to all three continents. Various case studies of attempts to promote aquaculture as stand-alone or integrated activities suggest that many of the constraints and opportunities are similar. A superficial review can quickly result in a conclusion that attempts to promote small-scale aquaculture in Africa and Latin America have failed and have little future. However, one holistic analysis of the causes of failure concluded that fish culture can become

TABLE 8.1

Issues and problems from the perspective of aquaculture promoters in Africa, Lat

Issues/Problems	Explanations/Comments
1. The development context	• projects have an aquaculture focus rather than being needs-driven • both needs identification and making the links between these and aquaculture is problematic • lack of awareness of off-farm factors and other livelihood options
2. Lack of sustainability of project efforts, including collapse of infrastructure	• inadequate assessment of limitations and priorities of host institution • inadequate involvement of all stakeholders in needs assessment and problem identification • infrastructure development focus
3. Problems in extension services: • poor morale • unable to reach farmers • inappropriate advice	• lack of incentives, little participation in decision-making, dependence on allowances • training has been technically and fisheries-based
4. Weaknesses in monitoring and evaluation	• lack of clarity concerning overall objectives and mechanisms for their achievement • failure to incorporate intra- and inter-household resources • lack or inconsistent data collection • projects over focus on data collection; unreliable and inconsistent data storage and use • lack of understanding of demand and benefits to consumers
5. Farmers do not respond as hoped: • failure to adopt • poor management	• aquaculture may be attractive and adoptable by only a limited number of farmers • fish production below the technical optimum may meet farmers' needs • water resource development may stimulate other uses of water that meet farmers' needs better • better technical advice/knowledge base required by farmers for improved yields • limited capacity to improve yields because of resource constraints, physical factors etc • better-off farmers benefit most, poorest people least

established as a valuable part of rural economies (Harrison, 1994; Brummett and Williams, 2000) and this has subsequently been demonstrated in parts of southern Africa (Van der Mheen, 1998). Another issue is the degree to which success is often measured in terms of project outcomes, which can be different to evaluation in terms of the needs of farming households. Many farmers in Asia have begun aquaculture without contact with foreign or government sponsored 'projects' and evaluation of impacts of individual projects can obscure a broader-based phenomenon.

Aquaculture in Africa and Latin America covers a wide range of culture systems within variable social, economic and ecological conditions. The promotion of rural, pond-based aquaculture in both regions has often failed, as have many other aspects of rural development, through misconceived foreign aid projects that have not focused on the real needs of the beneficiaries.

Progress in developing integrated livestock–fish in both rural Africa and Latin America has been slowed by a failure to recognise and adjust to failure (Harrison *et al.*, 1994). Although aquaculture in sub-Saharan Africa produces a tiny proportion of the world's cultured fish <0.5 percent (Lazard and Weigel, 1996), aquaculture is traditional in Ghana (Prein and Ofori, 1996) and elsewhere and survives in subsistence form in many countries. It remains an important potential focus for rural development. Demand for cultured fish varies greatly in Africa, depending on the value of fish as a regular food item and the availability of natural fish stocks or cheap imported fish (Lazard and Weigel, 1996).

In certain countries of Africa and Latin America with suitable infrastructure and international connections, high-input intensive aquaculture geared towards export has become established. Atlantic salmon in Chile and intensive cage and raceway-based tilapia production in Zimbabwe and Costa Rica, respectively, are well-established, typically in a vertically integrated mode that parallels that used for broiler chicken. In Columbia, growth in demand by better-off consumers has made feed-based aquaculture an alternative investment to monogastric livestock. In such cases, richer people control both production and consumption and the impact of the industry on poorer people is minor.

A comparison of the development of fish culture in Asia with Africa and Latin America in terms of the perspective of both the promoters and the farmers is instructive (Table 8.1). It suggests that many of the constraints to adoption

merica and Asia

Recommendations

- participatory research on needs for and value of aquaculture in specific contexts
- see 3 below
- livelihood analysis

- understand institutional legacy: how and why projects fail
- stakeholder analysis
- assess proposals for infrastructure in light of potential to meet development needs
- focus on institutional strengthening including managerial training and planning capacity
- revise project approaches to make them more flexible
- Reassess options for developing and extending information to farmers
- encourage private sector options
- ensure that aquatic resource R and D is incorporated into general rural development extension models
- ensure that aquatic resource R and D is incorporated into general focus training locally and towards participatory approaches that seek to strengthen linkages with ARM in overall livelihoods of the poor
- introduce relevant and measurable indicators

- needs analysis of target group and responsive extension advice
- careful selection of target group for promotion of aquaculture

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of productive aquaculture are similar, as is the integration of fish culture with livestock. An important point is that development of aquaculture in the three regions has not been homogeneous; the level of aquaculture development in Cambodia among poor rural people is little different to that of similar groups in many parts of Africa and Latin America

High demand for fish, often related historically to high human population densities of river valleys and deltas, and a reliance by such flood-affected people on fish to meet nutritional needs, has clearly been an important stimulus to aquaculture. Rural population densities in Africa can reach levels found in Asia and in such areas a greater reliance on livestock and their manure management is found (Lekasia *et al.*, 1998) Such population concentrations tend to be in highland areas, such as in the Kenya Highlands, where there is less traditional reliance on fish however However, aquaculture is largely a recent phenomenon in Asia, even in areas where it is now common (Edwards, 1996; Lewis, 1998) Small ponds, often the result of the removal of soil for construction, may be a more common feature of land-holdings in flood prone areas of Asia This inevitably reduces entry costs and risk, making attempts at fish culture more attractive. In Malawi, even small ponds are uncommon and an important investment for average small-holders, the majority of which have land-holdings of less than 1 ha (Noble, 1996).

Aquaculture development to meet local needs for food fish can be categorized into three stages on all three continents (Box 8.a). The recent acceleration in uptake of rural aquaculture over the last two decades in areas where it has occurred traditionally, may be linked to earlier

BOX 8.A

Stages in aquaculture development to serve local demand

Despite differences in current status of aquaculture and its perceived success, the needs and constraints of smallholder farmers that could potentially adopt aquaculture as part of their livelihood strategy in rural Africa and Latin America are remarkably similar to Asia.

STAGE 1

- **Little aquaculture adoption, enough wild fish. Early adopters are entrepreneurs, often ethnic or religious minorities. Limited demand, indigenous fish preferred.**

STAGE 2

- **Early adopters become seed producers; competition among food fish producers stimulates integration with livestock and other resource uses.**
- **Secondary, more numerous adopters of aquaculture, many retain a subsistence approach and ponds are multipurpose. Characterized by a broadening range of how aquaculture benefits people, especially the poor, through service and consumption. A minority develops towards a more commercial focus.**
- **Vertically integrated operations introduced but often fail as market conditions are undeveloped.**

STAGE 3

- **Shrinkage in number of operators as low input-output fish production has a further reduced role in livelihood systems; more off-farm labour, better infrastructure reduces role of pond as on-farm reservoirs and food production generally.**
- **Commercial and vertically integrated concerns compete, driving price of fish down. Sustainability of household-based commercial production and integration with livestock depends on 'macro' factors such as feed prices and environmental controls.**
- **Early adopters may use assets to diversify away from food fish production to ornamental fish production or unrelated services, urban/professional livelihoods.**

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adoption by a small minority and these may be more numerous and concentrated in Asia than elsewhere. Examples of all three types may be found in Africa, Latin America as well as Asia

Information needs

The need for appropriate information to allow households with few resources to adopt aquaculture 'successfully' has rarely been appreciated by promoters. Some observers have linked the failure of African aquaculture to an absence of a tradition of livestock management in general in which fish are treated in ponds similarly to small livestock i.e. left to fend for themselves and used for special needs (Hickling, 1971; Harrison *et al.*, 1994). But this is a similar situation in much of Asia where there is also little indigenous knowledge about aquaculture among the many rural households for whom it could be an option. The key gaps of knowledge that affect African farmers also inhibit small-holder fish culture in Asia. Commonly, people dig ponds with initial enthusiasm but little or no nutrients are used in the pond and fish yields are low. Such under-fertilization, either through poor access to nutrients or limited understanding of the concept, often leads to expectations remaining unfulfilled. Poor stock management in which seed with low resistance to predation are under or over-stocked is also common. This again may partly be related to a lack of knowledge but it may also indicate the farming household's motivations as indigenous carnivorous fish may be preferred to cultured fish species. Lewis (1997) reports that lack of knowledge rather than credit constrained poor households managing small ponds and ditches profitably for aquaculture in Bangladesh.

Prolonged culture cycles are also a widespread phenomenon. The tendency for farmers to hold fish for extended periods has been related to the pond being viewed as an asset and as a savings bank rather than as a unit of production. Poor harvesting technique or equipment and a lack of knowledge about growth and breeding patterns have also been implicated (Harrison *et al.*, 1994). A similar tendency is common among small-holders in Asia, for whom the pond is an important social asset as a larder or convenience store, especially if regular food needs are met in other ways. Usually, and especially where the culture of wild fish is traditional, the availability of skills and materials to catch fish is not a constraint. However, the widespread availability of very cheap modern synthetic net material in rural Asia may be an important difference to large areas of Africa and the Americas.

Institutional constraints

The capacity and sustainability of institutions working to promote aquaculture are key factors of success or failure. A major constraint to institutions working effectively to improve poor household's nutrition and income through aquaculture has been their technically-led approach (AIT, 1994). This is an aspect common to development efforts almost everywhere. Until recently, this was the case as much for national agricultural research centres as for international agencies. Furthermore, linkages and 'active partnerships' have often been lacking between these types of institutions and field-level organizations that have contact with large numbers of rural households. Lewis (1998) describes the institutional constraints to effective development for the poor in Bangladesh under conditions of 'resource constraints', not resources constraints for poor farmers but for competing professionals, and this country has one of the developing worlds' best financed programmes for promotion of rural aquaculture. As Lewis (1998) wrote: 'it is tempting to suggest that ICLARM and FRI need each other far more for the individual institutional survival of each agency than the average low income farm household in Bangladesh needs new technology for aquaculture'

Although participatory methods that work within the social and economic constraints of the target beneficiaries are required, a lack of

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relevant, generic information has been a common need of grass-roots development organizations working with farmers almost everywhere. This is often as true for livestock development as for aquaculture. Applying concepts, techniques and management to specific conditions in partnership with the beneficiaries is a complex and highly skilled task. A major problem is that the skills to do this are not taught at most universities or colleges; the much greater range and availability of institutions delivering education in aquatic resource management in Asia than elsewhere has not returned the expected benefits. Typically the focus is natural sciences alone and Masters level graduates have little if any direct experiece at the village pond side (Lewis, 1997). Improved training of field-level staff that focus on holistic and interdisciplinary skills are an urgent need throughout less developed countries.

As a general rule, human resource development precedes natural resource development and this is best carried out locally (Brummett, 1994) The current reliance on limited numbers of poorly trained and motivated extension staff to promote aquaculture occurs throughout the developing world. This has been a major constraint in both Asia and Africa. For example, the national country-wide extension service in Bangladesh is based on one extension officer in each *thana*, a local government unit with about a quarter of a million people (Lewis, 1998). Perhaps inevitably, especially as production targets rather than poverty reduction have tended to drive extension efforts, the focus in many countries has often been on richer, more accessible farmers

Regular and prolonged contact does not necessarily result in effective adoption, especially not if the farmers' needs were ill-understood and/or extension agents' information inappropriate. The lack of long-term, field level implementers in a project in Guatemala was identified at the time as a major constraint to success (Castillo *et al.*, 1992), but post-project evaluation has recently suggested that lack of technical knowledge was not the major reason for farmers neglecting or abandoning fish culture (Lovshin *et al.*, 2000)

Highly dispersed, rural households has been associated with the difficulty of effective extension in Africa but such conditions are also common to many under-resourced, conventional extension services in Asia. On-farm, group-based training is an effective and practical solution and also an approach that has proved more relevant and cost-effective in places with higher population densities. Even when limited budgets for field-level, extension staff and operating budgets have constrained the impact of programmes to actively promote fish culture in rural areas, a consistent presence can, over time, be an important stimulus and support for early adopters. This has been demonstrated by both government and non-government efforts in Northeast Thailand (Little and Satapornvanit, 1996)

Similar problems that have confronted institutions attempting to promote aquaculture in Asia have been identified for the other two regions. Indicators of rejection of fish culture such as abandoned ponds and sub-optimal fish management are as typical of rural Asia as they are of Africa and Latin America

In the past, there was a similar emphasis on renovation and rehabilitation of Government ponds, farms and hatcheries without consideration of their effectiveness and their longer-term sustainability. Planning to ensure realisable objectives, operating budget and staff motivation have often been insufficient. Prevailing institutional cultures that are not responsive to the needs of poor farmers in rural areas are often a fundamental problem Such factors have often been made worse by aquaculture being located within fisheries departments or D'eaux et Foret, rather than within a broader agricultural extension service (Harrison *et al.*, 1994; FAO, 1997a)

Development of managed aquatic resources is not usually part of a coherent national plan and opportunities for synergism are lost; aquaculture in particular, is typically accorded low priority Structural adjustment, or roll-back of government support for extension also takes a toll on the conventional extension approach. Even when fisheries development is accorded a high priority, performance is often affected by a limited capacity of the institutions to plan and manage,

and poor co-ordination within and between organizations, including many internationally funded and staffed donor projects

Better integration of institutions promoting household-level livestock and fish culture could have many tangible benefits, particularly in poorer countries with few resources. This has been demonstrated in the Lao PDR where responsibility for extension of livestock and fish production by the same local level extension staff has proved beneficial (Innes-Taylor, pers comm.).

Research is typically separated from extension and focused towards on-station, bio-technical issues rather than being responsive and problem-orientated. Even if research on 'low input' systems is prioritized, on-station research will still often mis-target research efforts (see Box 8.B).

Many of the institutional constraints to development are exacerbated by the project approach of foreign donors. Indeed the complexity of issues, mixed motivations and negative interactions between various 'partners' in development projects are often major causes of failure to impact positively on target beneficiaries. The need for leadership from local actors rather than external development agencies *per se* has been identified by Brummett and Williams (2000) as a key requirement to stimulate successful rural aquaculture. Generally in Asia this has not required 'research' but rather the introduction of ideas and concepts and their adaptation by progressive farmers.

The 'critical mass' among the private sector in large parts of Asia is now a major driving force for development. It can give the impression that institutional constraints were, and remain, less important here than in Africa or Latin America However, adoption of aquaculture by poor people remains far from complete in Asia and institutional constraints are, as in Africa and Latin America, are of major importance and largely unresolved (Box 8.C).

BOX 8.B

Poorly targeted research for resource-poor farmers

- **Standard recommendations for semi-intensive aquaculture in India were highly successful for resource-rich farmers in Andra Pradesh but largely irrelevant for the resource-poor.**
- **Fertilizer regimes developed at AIT for optimal production were not adopted by a large proportion of risk-averse farmers in Northeast Thailand, despite proven and potentially high returns (Turongruang *et al.*, 1994). This has since been exacerbated by the recent economic crisis which resulted in a sudden and steep rise in the price of inorganic fertilizers.**
- **Project-based research aiming to support fish culture by smallholders in Central and Northern regions of Malawi was based on animal manures that were practically unavailable to the farmers.**

Source: Dickson and Brooks (1997)

BOX 8.C

Institutional issues constraining aquaculture development common to Asia, Africa and Latin America

- **No review of history and mistakes.**
- **Emphasis on infrastructure rather than solving persistent managerial/technical problems.**
- **Focus on over-ambitious fish yield targets; often not set in any framework of overall nutritional/cash needs.**
- **Lack of realistic and measurable indicators.**
- **Extension service become data collectors for sophisticated, unsustainable data-bases.**
- **Poor quality of training for extension staff, dissemination of inappropriate messages.**
- **Extension staff mainly biologists not trained in extension.**
- **Close linkage with fisheries rather than agricultural extension.**
- **Promotion through unsustainable provision of inputs and services.**

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Seed supply

Poor seed supply has been a major constraint to sustainable adoption of fish culture in all three regions. Adoption of fish culture in the past in traditional areas of Asia depended either on capture of wild seed of Chinese and Indian major carps from rivers, or household-level spawning of common carp. Induced breeding of carps in the 1960s led to available seed of these species, at least adjacent to large, central hatcheries. A focus on self-sufficient strategies based on mixed-sex tilapias has been most successful in many countries in both Africa and Latin America and they have also proved important in much of Asia. Technical specialists have long perceived a reliance on tilapias that breed within the culture system as both a handicap and opportunity for the development of aquaculture in Africa (Lazard and Legendre, 1996). Alternative species, which are more dependent on government hatcheries, such as carps and catfish have proved less sustainable. Projects in Cote d'Ivoire, Central African Republic, Congo, Cameroon, Madagascar and Niger promoting aquaculture around a fry production facility found a number of common constraints (Box 8.D), but these have also been identified as being relevant in much of Asia (Shrestha *et al.*, 1997). Where private sector hatchery production was stimulated, as in Cote d'Ivoire, and 60 percent of the fish stocked by the project were produced by farmers, continued subsidised central production probably constrained this private sector development. The same situation was also found in Northeast Thailand before private sector fry production boomed in the mid to late 1980s (Little and Muir, 1987)

BOX 8.D

Constraints to fish seed production in Africa

- **High operating costs of Government stations.**
- **Low levels of technical expertise.**
- **Logistical problems in dissemination of seed to farmers.**

Source: Lazard and Legendre (1996)

BOX 8.E

Promoting self-sufficiency of fish seed

Tilapia culture was promoted in both Panama and Guatemala to encourage self-sufficiency of seed and reduce dependence on government supplies of carps:

- **supplies of carp seed from government hatcheries in Panama were unreliable, community pond operators were trained in tilapia seed production techniques;**
- **after 14 years, most projects still raising fish were not self sufficient in tilapia seed and remained dependent on the government for restocking;**
- **a lack of water, difficulties in managing fry production on a community basis, and continued availability, often subsidised, of seed from the Government were major reasons for this;**
- **smallholders continuing to stock carps remained dependent on government supplied seed in Guatemala. Most of the aquaculture sustained was based on stocking mixed-sex tilapia obtained locally.**

Poor seed supply has undermined project-led, aquaculture promotion in Latin America and Asia. Government hatcheries were unreliable sources of seed but attempts to promote self-sufficiency among farmers, even of mixed-sex tilapias, met with uneven success (Box 8.E). If government-based carp seed production has proved largely unsustainable in Africa and Latin America, its success has also been patchy in Asia. It is likely that poor demand for exotic carps has often been underestimated as a major cause for this failure, which occurred in countries such as the Philippines and Sri Lanka. In countries where riverine carps are indigenous, such as China and India, their controlled reproduction

and that of other introduced carps became rapidly established within the private sector. Countries in which distribution of wild caught seed through trading networks pre-dated hatchery development, such as Bangladesh and Viet Nam, witnessed a particularly rapid spread

8.5 Theft and predation

Theft is a commonly mentioned risk to small-holders fish culture, restricting its adoption throughout the developing world. The fact that 'theft' may actually be caused by predation of carnivorous fish, mammals and birds is often overlooked. Theft from ricefields stocked with fish was a common constraint in Thailand and elsewhere where traditionally only the rice was individually managed and other foods common property (Little and Sataporn vanit, 1996) 'Redistribution', either through purposeful theft or accident through flooding to neighbours or extended family, is also common in Africa and Asia. Aquatic environments make fish and other aquatic products more difficult and risky to manage than terrestrial crops. Escaped fish are almost impossible to reclaim as they cannot be easily marked for identification. Individual growth and survival is problematic to monitor, making strategic theft hard to detect.

Proximity of cultured fish to the homestead, or availability of male household members to guard isolated ponds, are important factors reducing the risk of theft, however.

8.6 Demand

The motivations for attempting aquaculture by small-holders in Asia mirror the range observed by Harrison *et al.* (1994) in Africa. Generally farming households will view the pond, and the fish in it, as part of a portfolio of assets and opportunities. Their strategies for managing and using the water, fish and other products depend on their resource base and needs. The availability of other livelihood options and relevant information are also critical to determining how farmers use their water resource. Farmed fish are an asset that can be used directly for home consumption or reducing cash expenditure on food. Easy access to cultured fish can also reduce the time spent catching wild fish. Products from the pond may be sold, bartered or given away, in expectation of later reciprocation.

The reasons for agencies to promote, and for the farmers to adopt, aquaculture are complex. The idea that successful small-scale aquaculture is commercial in Asia, as opposed to subsistence in Africa (Hecht, 2000), is simplistic. Low population density, abundant land and demand for fish initially motivated households to try aquaculture in Luapula, Zambia. Farmers were less concerned with fish production becoming a source of income than other factors. In contrast, resource pressures made income generation the main motivation for digging and managing ponds in Western Kenya. Markets and market channels were also better developed in the latter (Harrison, 1994). A similar contrast could be drawn between the market responsive farmers of Northern Viet Nam and subsistence-focused households in less developed and populated parts of Southeast Asia. In the subsistence economy of Rwanda, Hishamunda *et al.* (1998) found that tilapia culture benefited household welfare much more through income generation rather than home consumption as an enterprise within the farming system.

The amount of fish cultured by households may have less impact on diets and income than is often assumed. In Africa, farmers most successful at producing fish also obtained significant quantities of fish from wild stocks and markets (Harrison *et al.*, 1994). Fish culture had less impact on their household food security than households producing less fish themselves, but with poorer access to alternative sources. Aquaculture was promoted in Northeast Thailand for decades before the impact of the relatively small amounts of cultured fish were placed in context with the generally far more

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important quantities of fish purchased or caught from the wild (Prapertchob, 1989; Little and Satapornvanit, 1996)

Demand for any type of food reflects cultural norms, availability of substitutes as well as purchasing power and resource wealth. In much of Southeast Asia, fish consumption, by choice, can reach levels of 60 kg. caput^{-1} year^{-1} (Sverdrup-Jensen *et al.*, 1992). Clearly, rural households raising fish often have a range of options. Subsistence may still be the major objective of small holders raising fish, even when fish is highly marketable locally More than half of farmers stocking fish in Northeast Thailand sell no fish (AIT/DOF, 2000) and Lovshin *et al.* (2000) found that a similar proportion of smallholder fish culture in Guatemala was subsistence-based Farmers may also view entry into aquaculture as an option to reduce risks associated with declining abundance of wild stocks or to substitute cultured for more valuable wild fish in the diet (Box 8.F).

The need to intensify either livestock or fish production to meet food security and cash needs is still undeveloped in parts of both Africa and the Americas, but this reliance on natural populations or extensive production methods also remains the case in parts of Asia (Little and Edwards, 1997). Traditional livelihoods have often been affected by opportunities in urban markets but have yet to develop towards more intensive food production. As a result, interest in livestock and fish production may remain low even while households lack food. In parts of Ghana, the importance of highly marketable bush meat constrained interest in small livestock that are commonly raised but used mainly for ceremonies and as an emergency reserve (Ruddle, 1996) Project-affected households farming fish tended to sell their game and eat their own cultured fish

Clearly the development of aquaculture will be slower where fish and other aquatic products are a less important part of traditional diets. Levels of fish consumption are far higher in parts of Africa and Latin America than many areas of Asia. In Iran and Pakistan for example, traditional consumption levels are very low and mainly limited to consumption of marine fish by coastal communities; inland populations in these semi-arid environments traditionally have little access to freshwater fish Large-scale irrigation of inland areas of these countries, such as the Punjab in Pakistan, did little to change traditional attitudes and fish consumption levels have remained low. Demand for fish in these countries is growing more rapidly among urbanized populations than in rural areas

BOX 8.F

What happens to farmed fish in rural Africa, Latin America and Asia?

Farmed stocks contribute to household food security through:

- **direct consumption to substitute for declining wild stocks;**
- **direct consumption allowing more valuable wild stocks to be marketed off-farm;**
- **indirectly through sale for cash as less valuable, small wild fish are available and used for subsistence.**

Multi-purpose use and benefits

A common phenomenon is the value of ponds being recognized by rural people in more holistic terms than planned by promoters working towards fixed technical goals. Success in meeting demand has to be considered in more holistic terms than fish yields alone. Production levels of fish in both household and community-level ponds in Latin America were not sustained at levels that met the expectations of their promoters. Ponds were managed principally as a source of irrigation water for rice and/or vegetables once project support was withdrawn. They were also an important resource for watering livestock. Evaluating the contribution of

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fish alone towards household food security is therefore misleading. Ruddle and Prein (1998), modelling the value of pond water in Ghana, found that water used for vegetables had more impact on cash generation and household food security than the limited output of fish from small ponds. Even significantly increased levels of fish production were found to have marginal impacts Increased interest in ponds during prolonged periods of drought, principally for the value of the water stored for vegetable and livestock production rather than stocked fish, was common to smallholders in Malawi (Noble, 1996) and Northeast Thailand (Surintaraseree and Little, 1998). The value of the 'fishpond' as a multipurpose resource has been accepted in Asia perhaps longer; water resource projects were occasionally 'disguised' as fish culture projects in the 1970s and 1980s to fit with donors interest in aquaculture development. The major purpose from the outset, however, was rehabilitation of community water bodies to meet a variety of needs. Holistic analyses of the role of pond and ricefield-based aquaculture within diversified farming systems elsewhere in Asia point to their importance as a multi-use resource, particularly where off-farm irrigation is lacking.

8.8

Beneficiaries

Non-fish farmers

Efforts to promote aquaculture have typically focused on a sub-set of individuals within communities and, indeed, within households They have often ignored broader resource issues, and benefits and disadvantages, that result for the wider community. Clearly access to, and exploitation of, community water and nutrient resources by some individuals can impoverish others. However, non-fish producers may benefit from aquaculture through improved availability and lower priced fish.

Reduced access to land and water by poorer people as it is appropriated for use for aquaculture by richer people appears to be a significant emerging problem in areas of resource scarcity where, incidentally, conditions are often suitable for aquaculture. Use of low-lying wetland areas (*dambos*) in Luapula, Zambia for fish pond construction stimulated a scramble for resources in which other uses and users were excluded (Harrison *et al.*, 1994). The same is clearly an impact of successful aquaculture adoption in Bangladesh where drainage of common property water bodies for privately-owned ponds and encroachment by rice growers is reducing the availability of small indigenous species of particular importance to the poor (Thilsted *et al.*, 1997).

Intra-household

The focus on extension of aquaculture technology to male head-of-households has been questioned for a variety of reasons in Africa, Latin America and Asia. Again, there is probably as much variation within as between these continents, with respect to how decisions of resources are used and benefits distributed. Unequal opportunities within the household to use and inherit land (and ponds), obtain credit, market or distribute products and access information occur widely. Gender-blind planning, with negative consequences, has typically been the norm as has a failure to understand other age and power relationships within and between households. Intra-household relationships may be particularly important where food is scarce. Insufficient staple and complementary crop production underlying the malnutrition of resource-poor households farming fish in Ghana are exacerbated by cultural factors governing intra-family food consumption.

Community and group-based development

Promoting aquaculture to groups of farmers has been tried with varying success in all three regions. Sometimes groups are used as the extension focus for either individual household-based production, or for a community-based activity. Efforts to ensure equitable development of aquatic resources have often been an incentive to promote community or group-based aquaculture. A community approach may also result from a lack

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of potential for the targeted group to have individual ponds, or the fact that the water resource already exists but is underutilized. Rural communities are often situated around natural water bodies. In addition to them being a source of water, they also typically act as drainage basins for livestock and other wastes, and are often highly productive as a result. Sometimes, often as part of efforts to integrate rural development, livestock components have been actively promoted, such as in the Village Fish Pond Project in Northeast Thailand (Box 8.G)

A range of management issues reduce opportunities to intensify production, although provision of alternative domestic water supply overcomes some of the problems. Many similarities can be found with the situation in Panama (Box 8.H) where efforts to promote the use of community ponds for fish production have resulted in multiple uses and products being developed, but fish yields well below those technically possible

Community approaches to extension have proved successful in Asia. In Bangladesh such are the social constraints to targeting aquaculture development to the poorest in the community, a whole village approach has achieved good results. Such community development is not only efficient in terms of extension effort, but the inclusive approach also ensures that social tensions are not exacerbated between wealthier people and poorer groups. The participatory techniques that support the approach have also allowed social constraints, such as participation by women in pond activities, to be overcome by encouraging peer support and evaluation (NFEP, 2000).

The relatively high retention of livestock integrated within community pond systems in Panama, albeit on a more extensive and less consistent level than envisaged by the project planners, is noteworthy. External factors (roads, feed availability and marketing opportunities)

BOX 8.G

Factors affecting the success of integrated livestock aquaculture in community managed water bodies in Northeast Thailand and Lao PDR

- **The nature of current interaction with livestock. Conflicts arising through access of large ruminants to wallow in community ponds are resolvable through access restrictions.**
- **Spatial location of community ponds and settlement pattern of the community[1].**
- **Traditional management and feeding systems e.g. free-range ducks, liable to theft of eggs and animals led farmers to pen ducks in the homestead plot, reducing access of ducks to water body once intensified[1].**
- **Use of pig manure allowed the benefits of integration to be appreciated before pigs were relocated to household-managed ponds. Many households abandoned pig production after initial subsidies were withdrawn[1].**
- **Requirements for an alternative water source for domestic purposes were resolved through provision of shallow well nearby[2].**
- **The level of regular stock management and harvest.**
- **Active village committees, representative of the community and reactive to their needs are critical. Benefits need to be seen to be accorded to the community as a whole, rather than benefit a small elite.**
- **Continued access of the poorest to non-fish resources e.g. aquatic plants, crustaceans, amphibians and snails[4].**
- **Management of stocked community ponds and reduced fishing effort resulted in an increase in the role of the pond as a refuge for wild fish species with potentially beneficial effects on seasonal rice field fish yields[5].**

Sources [1]AASP (1996), [2]Garaway (1995) [3]Garaway (1999), [4]Lorenzen *et al* (1998a), [5]Lorenzen *et al* (1998b)

had become more positive since project inception. There is also evidence that access to benefits had become more concentrated towards single owners and related kin. The focus on using ponds for rice production suggest that this was a de facto 'privatization' of the community resource (Lovshin *et al.*, 1986)

The timing of interest in intensified fish production is often critical. An expected future shortage of fish stimulated attempts at low input community aquaculture in Nigeria, but the relatively high residual wild fish availability and a poor understanding of the social issues undermined the attempt (Thomas, 1994). The constraints identified to (Box 8.I) have also occurred in Asia with similar agro-ecological and social environments.

Comparing the regions

A range of factors can be identified that have influenced the belief that rural aquaculture has met with more success in Asia than either Africa or Latin America (Box 8.J). The analysis suggests that a generally higher population density in Asia and greater relative reliance on aquatic food in most rice-dominated agroecologies explains much of this dichotomy, but that aquaculture integrated within the farming system can often be relevant to the needs of poor rural people. The basic constraints to adoption of aquaculture by this group, and its integration with livestock, are similar.

BOX 8.H

Promoting community-level aquaculture in Panama

In Panama the promotion of aquaculture among organized groups of poor farmers (campesinos) was supported through training, assistance in pond excavation and setting up integrated livestock and crop production over a two year period

Early evaluations found that:

- **groups worked best when the community was not highly stratified;**
- **groups in communities with relatively few public and private commercial services;**
- **groups with their leadership drawn from within, rather than elites, were most sustainable.**

After a period of 14 years, an evaluation found that adoption had not been sustained at the level, or in the manner, planned. Fish production levels had declined and direct nutritional benefits from fish judged minor since the time of the project. However, the community had generally adapted ponds to produce rice, which were often integrated with fish culture, and continued to use them as a focus for livestock and fruit production.

Unfortunately, an evaluation of the benefits from these activities was not presented but it seems likely that the current utilization was meeting some needs of the communities involved.

A range of social, economic and technical factors were identified to explain this, all of which could be drawn from projects in Asia:

- **lack of timely availability of fingerlings hindered the efficient use of ponds;**
- **groups found it difficult to manage livestock, especially financing inputs. Livestock numbers and management were 'sub-optimal' but this was the only major source of nutrients entering the ponds in community projects;**
- **poor site selection, especially when water retention was poor and culture seasonal;**
- **out-migration of the young, reducing labour availability e.g. men leaving for construction industry;**
- **difficulties in managing loans;**
- **land ownership issues of community projects.**

Source Lovshin *et al* (2000)

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BOX 8.1

A failed attempt at community aquaculture in Nigeria

Situated in the Hadejia-Nguru wetlands of Northern Nigeria, a community approach to aquaculture was promoted in a village of 1200 people. Although fish production per hectare was 171 percent greater in managed compared to unmanaged ponds, and returns to labour were favourable to alternatives, the project was not sustained:

- the technology was 'simple' i.e. wild seed surplus to catches of food fish stocked in ponds fertilized with cow manure;
- poor levels of community participation were related to:
  - a lack of any custom of community fishing, and
  - inappropriate management structure, despite being based on indigenous institutions and maintaining linkages with State organizations.
- poor levels of education (literacy and numeracy) prevented the community monitoring the project effectively;
- fishers were reluctant to contribute even low value fingerlings because they were not convinced of a return;
- change in how the fish were harvested and disposed of conflicted with traditional practices;
- reduced rights of access to certain groups which increased social tensions between ethnic groups;
- aquaculture didn't meet the needs of particularly the poorer people who would rather catch 1 kg of wild fish than obtain more fish later.

Source: Thomas (1994)

BOX 8.2

Factors influencing the relatively lower success of rural aquaculture in Africa and Latin America than Asia

1. Greater dominance of 'projects' in evaluation of success, criteria for success and farmers attitudes to inputs. Greater importance in the 'culture of development' to adoption.
2. Less availability of markets and market channels for inputs such as cheap, synthetic net materials.
3. Less long term consistent attempts to promote aquaculture by Government and NGOs.
4. Less core resources developed in terms of early adopters that can support new entrants, although where they have, suggestive of a similar role to that in Asia. This may be related to (3) and a lack of traditional wild seed collection and use.
5. Lower population densities and need for cultured fish and on-farm irrigation also reduces effectiveness of change agents in aquaculture and other new activities.
6. Less traditional importance of freshwater fish in the diet. Relatively smaller proportion of the population in Africa and Latin America where fish and aquatic products constitute a major proportion of dietary animal protein.

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9

Future Directions in Livestock-fish Integration

The first questions addressed in this final Chapter relate to the opportunities and major constraints facing the continued development of intensive livestock and fish production. The factors stimulating these trends are examined and critically analyzed and the case made for novel or renewed closer integration. The relative opportunities for livestock waste use through aquaculture are then examined and contrasted with alternatives such as their value for crop production and energy generation. Trends in food consumption and water use are reexamined, and opportunities and threats to integrated livestock-fish production considered.

Opportunities for aquaculture and livestock within nutrient-poor, small-holder systems are then reviewed given our analysis in earlier Chapters and new approaches to multipurpose water use.

Demand and globalization

Global trading networks are increasingly challenging the concept of self-sufficiency and consumption norms. Much of the increase in demand for livestock and fish products is expected in LDCs, both in rural and urban areas. Although rural communities in LDCs are expected to grow further before stabilizing, full-time farming in many agro-environments is likely to decline. Demand for both livestock and fish products can therefore be expected to increase in rural as well as in urban and periurban environments where demand will climb even more swiftly.

Applying conventional sources of feeds and production systems is expected to allow response to these demands in the short-term, largely through increases in grain and protein feed crops in Brazil and the USA and a few other food surplus countries. In the medium-term, growth in demand may stagnate in countries

with limited reserves of foreign currency, large populations and small capacity to increase crop production further. Countries such as Japan, Korea and Malaysia that import large quantities of feedstuffs will be particularly sensitive to global shortfalls in livestock feed ingredients (Farrell, 1996)

Commercial livestock production will increasingly be drawn to areas of relative advantage, especially those for processed products, often to areas within reach of ports for shipments of feed, or close to the areas where the feed is produced. Stringent environmental regulations and shortages of high quality water, in contrast, will also restrict intensive aquaculture. This will draw international investors towards less-densely populated regions and could impact relatively severely on the natural environment.

9.2 Feed resources

The major single limiting factor to increased livestock and fish production will be availability of feed. Competition for feed occurs at both the local level, usually for grain by-products such as brans and oil cakes, as well as the national and international level for concentrates of cereals, pulses and animal products (fish and meat meals). Fish meals and oils, being dependent on wild stocks, are particularly limiting for feedlot livestock and feedlot fish, particularly salmonids in colder countries and shrimp in the tropics

Increases in the real price of concentrates are expected as globalization of world trade occurs, wild fish-based products become relatively scarcer and demand for livestock products soar in industrializing parts of the world. This will favour the most efficient users of concentrates in both livestock and fish production sectors and substitution of high cost ingredients; indeed the percentage of fishmeal in livestock feeds has fallen markedly in recent years.

Estimating the quantity of feed ingredients required in the future depends on how many animals are housed intensively, and how many remain extensively managed (Farrell, 1996). Currently a large proportion of livestock are raised extensively in developing countries although the overall trend is rapidly towards intensification.

Improving feed efficiency is a major challenge to animal and fish nutritionists, particularly for intensively raised monogastric livestock and fish. Increased feeding efficiency has already allowed the amount of livestock production to increase faster than demand for concentrates over the last decade. If the productivity gap can be closed between OECD countries and China, and other developing countries with rapidly growing demand for pig and poultry products, greater production can be expected without large increases in demand for concentrates (de Haan *et al.*, 1997).

Broader definitions of efficiency may be more relevant in the future. Feeding efficiency, which is typically expressed as a FCR, gives little information on the quality of the feed or how feed is used within a broader farming system. Scavenging animals fed a supplementary feed produced on-farm, usually grains or grain products, will have poorer conventional conversion efficiencies than intensively-raised animals fed compounded diets. Wastes derived will also generally be of lower value for aquaculture. However cash outlays may be negligible and farmers, by using low cost grains in this way, add value to their farming output in an 'efficient' manner. The prospects for more use of concentrates and role of 'improved' strains by small-holders is considered later

Grains and grain products are also the largest component of compounded livestock feeds, accounting for 70,75 and 65 percent of modern pig, broiler and layer diets, respectively (Farrell, 1996). Concentrates, typically comprising soybean and fish meals together with a range of higher cost additives (vitamins and minerals) is added to meet the exacting nutritional needs of breeds selected for their performance on such feeds. Feed conversion efficiencies are high but many factors, such as access to concentrates and markets and pricing of inputs and products, limit small-holder involvement.

The overall efficiency of both traditional and modern feeds and strains can be improved through their integration with fish. If overall production per tonne of feed is considered, integration can be seen to dramatically improve overall efficiency. Similar gains are possible when feedlot fish culture is integrated with semi-intensive culture of carps and tilapias.

Development away from conventional, grain-based livestock and fish production systems has been identified as a need for the humid and sub-humid tropics where cereal deficits are common. Alternatives include greater use of feeds traditionally used in some areas e.g. sweet potato and cassava, and development of unconventional feeds e.g. sugar cane, green pulse fodders, sugar palm (Preston, 1990).

9.3 Intensification not concentration

Sustainable recycling of wastes produced by industrial livestock systems must be attractive, both financially and environmentally. Integration of aquaculture into such systems can be attractive; current linkages between better-off peri-urban livestock farmers, with little land and a lot of waste, selling waste to farmers specializing on horticulture or fish, already exist in parts of Asia. Good infrastructure (especially roads) and an enabling environment for the trading of inputs, products and by-products are necessary to make such options viable.

The relatively high value of nutrients and few technical alternatives for waste disposal have probably encouraged the development of these systems where they are important. However, in many areas of high livestock concentration, nutrient surpluses are often common. Recyling on the limited land areas within easy reach of producers can result in excessive loading, leaching and pollution of surface water. High water content of livestock wastes and transport costs limit the distances to which they can be used. Mineral fertilizers are often cheaper and easier to use.

The factors that have encouraged livestock production to become concentrated need policy changes to stimulate more rationale use of livestock wastes (Box 9.A). Improved overall efficiency of food production should be the aim, with an emphasis on reducing waste outputs of the *whole system*. The growth of industrial systems has been greatly stimulated by policy distortions in Western Europe, exacerbating the relative advantage of livestock producers that concentrate in the Netherlands, Brittany and other areas of Northwest Europe. In Singapore, the negative impacts of concentrated, intensive pig production has led to its abandonment (Box 9.B). These incentives may be unaffordable in developing countries, but poorer infrastructure and access to markets encourage livestock producers to concentrate in peri-urban areas resulting in similar concentrations of livestock operations and negative impacts. The same phenomenon has occurred in intensive aquaculture where the carrying capacity of the local environment has been exceeded such as the sites of intensive cage culture in reservoirs in West Java. The relative sensitivity of most cultured aquatic animals to changes in their environment may be an important factor in self-regulation but often not before long-term

BOX 9.A

Possible policies to discourage concentration of intensive livestock and fish production

- **Reduce policy distortions such as low import tariffs on cereal substitutes and high domestic prices for beef and milk in Europe (Steinfeld *et al.*, 1997).**
- **Tax effluents from livestock and fish production.**
- **Classification and zoning of watersheds with production ceilings linked to levels and efficiency of on-site waste reuse.**
- **Reduction in regional inequalities in infrastructure development.**
- **Effective information dissemination to disadvantaged areas.**

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TABLE 9.1

Measures to intensify livestock and fish production without spatial concentration

Problem	Appropriate measures
Increased urban demand leads to concentration and intensification of livestock production	• Discourage mega-urbanization; encourage provincial urban growth • Limit size of livestock holdings • Encourage agribusiness to target small-scale operations with appropriate concentrate formulations, germplasm and veterinary support
In areas of high livestock/fish densities, high pollution occurs	• Introduction of pollution levies and regulations
Concentration of livestock/aquaculture due to availability of feed	• Improve infrastructure, allow markets for feeds to operate competitively • Identify and develop alternative types of livestock feed • Encourage local processing of crops and crop products
Concentration of livestock/aquaculture due to restricted access to markets	• Improve infrastructure • Encourage local processing industries
Technology developed for industrial production only	• Target small-holders for R&D efforts • Adopt farmer-first paradigm by extension services • Ensure free competition in markets for inputs and outputs
Dichotomy of industrial and back-yard systems	• Increase availability of appropriate information to small-holder livestock farmers

environmental and social damage has occurred A range of measures may be useful to intensify livestock and fish production (Table 9.1) without spatial concentration.

Peri-urban integration

Many forces are stimulating more technically advanced integration of food production. Increasingly, both public opinion and safety, concern for animal welfare and zero pollution must be satisfied. In the western world, pollution prevention and alleviation will drive both public and private investment in food production into the foreseeable future and zero pollution will become the target. In land-rich, warmer countries lower technology solutions will continue to develop, subject to stricter adherence to safety issues. Global trade will increasingly reduce the current differentials between hygiene requirements in LDCs and the developed countries and, meeting the media-fueled, consumer expectations will be critical to development of sustainable food production of all types

Impacts

- Stimulate equitable growth and development; reduce urban:rural inequalitities
- Increase in part-time farming
- Intensification and increased efficiency without drastic declines in spread of livestock operations
- Increased opportunities for cost-effective integration within wider farming systems
- Reduced likelihood of intensification of fish culture
- Reduced need for reliance on inorganic fertilization
- Competitiveness of small-holder operations maintained
- Adoption of no-effluent systems and linkages with nutrient-poor, [illegible] food production
- Development of intensive, integrated fish culture based on tolerant species
- Increased employment opportunities
- Diversify farming systems, land use by using unconventional plant and other feed materials
- Increased employment opportunities
- Improved opportunities for integration in more diversified food production systems
- Increased employment opportunities

- Small-holders improve livelihoods by improving food production systems
- Small-holders enhance livelihoods by improving food production systems

In developed countries, biological processes have in some cases been superseded by use of industrial processes but the support costs may not be sustainable in the long term. Increasingly a return to, or combination with, microbial, fungal or invertebrate treatment processes for wastes, or as part of the production process, look likely

The development of export-led livestock production, in which processed by-products remain in-country and are used to support fish culture, has obvious merits. This practice leads to efficient recycling of wastes at source, both production and processing, whilst generating high-value, low-cost animal protein in addition to foreign revenue.

Geographical range

Using fish culture as a component of broader food production systems has most potential in the tropics where temperatures remain elevated and stable year-round. However, wastes have been used traditionally for aquatic production in both the sub-tropics and temperate zones. The lower temperature regimes of tropical highland areas such as Rwanda, are also known to reduce aquatic productivity (Molnar *et al.*, 1996).

Trends in land and environmental planning suggest opportunities exist for aquaculture to be more central to waste disposal in the future. Variations in ambient temperatures through the year is an important design criterion for biological waste treatment of any type. The residence times of wastewater passing through stabilization pond systems in temperate zones are based on changes in seasonal efficiency. Poorly designed systems result in seasonal overloading and fish die-off, such as occurred in poultry-fish systems in Hong Kong (Sin, 1980). Integration of large pig production units and fish culture has occurred in Hungary and treatment of wastewater has been traditional in Europe and subtropical parts of Asia (Edwards, 1992). Ensuring optimal loading rates of organic waste, be they of animal or human origin, may require pre-treatment and storage capacity in most cases to ensure wastes are used efficiently.

The use of livestock wastes must be viewed within the context of further increases in organic waste production of all types and the likelihood of more stringent control of dumping, land fill and other methods of disposal. An increased role for artificial wetlands within urban and peri-urban landscapes would enhance flood control, wildlife conservation and wastewaster treatment. Integration of fish production is a traditional feature of such systems in some Asian cities. Incorporation of aquaculture within broader water and wastewater treatment and storage has become a major part of Israeli settlement patterns where water conservation has made the use of wastewater for secondary irrigation a necessity.

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BOX 9.8

Singapore phases out pig production

- High demand for pork in Singapore because the Chinese ethnic majority (78 percent) has a dietary tradition of consuming pork and it is now an indispensable part of their diet. Annual consumption levels are 35 kg. caput^{-1}.
- A total population of 2.5 million people lives in a total land area of 620 km^2.
- Over three decades the standing pig population increased from 400 000 animals raised mainly in small units scattered through rural areas (1960) to 750 000 before relocation to a single 650 ha site (1980). The Government then decided to phase out pig production completely by 1990.
- Incompatibility with urban growth: Location in and discharge of waste waters into catchment areas used for municipal water supply, disposal of solid wastes and malodours.
- Recovery and use of pig waste was hampered by the need to use water to remove wastes and cool pigs and led to dilute slurries (1 percent solids) that were difficult to handle and use without large areas of land. The predominantly muslim workforce also constrained handling of pig manure. Attempts to reduce water use failed when pig performance suffered under high ambient temperatures.
- Local demand for fresh rather than frozen meat made Singapore produced pork competitive with imports, even when pollution control measures were enforced, that added around 4 percent to production costs.
- Conventional, semi-intensive fish production would have required 7 500 ha of land to treat the wastes of the Singapore herd. Intensification following methods by Nuov *et al.* 1995, would have reduced this to 10 percent of this figure.

Source Taiganides (1992)

Use of animal wastes for other purposes

The major problem of animal waste disposal has stimulated research and development in developed countries towards alternative methods. Recycling by spreading on arable land has many constraints and has resulted in significant damage to groundwater resources and natural aquatic and wetland ecosystems Odour and the leaching of nitrates and other pollutants into groundwater has spurred legislation in Europe and in Singapore hastened the phasing out of intensive livestock production (Box 9.B)

A major problem is the sheer concentration of animal wastes, typically collected and stored as slurry, which is expensive to transport and treat. Most strategies require considerable energy to dry the waste. Separation and composting of manure solids and its use for high value horticultural container medium is possible (Inbar *et al.*,1993) but given the amounts have limited impact (Box 9.C).

On-site processing (drying, composting and fermentation) are options but are unlikely to be cost effective if low value soil conditioners alone are produced. However, the use of fresh manure to produce live feeds, primarily for fish and also a low-moisture, compost-like material for horticultural use has proved commercially viable (Nuov *et al.*, 1995). Farm mortalities and processing wastes are other major by-products of intensive livestock production that have often been disposed of in landfills or incineration, although local composting has been recommended by some. Rendering to meat meals has been a conventional approach for such products but is now subject to criticism by both consumers and legislators following the BSE crisis. Re-feeding of poultry litter and other wastes has been a standard practice in some areas (Chapman, 1994)

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BOX 9.C

Separation of solid and liquid waste fractions improves the efficiency of livestock waste use in farming systems

- **Efforts should be made to improve efficiency of feed in livestock–fish systems. Separation of waste feed from faecal and bedding waste is desirable in intensively raised livestock. Waste feed has a high direct feeding value for fish in semi-intensive systems.**
- **Solid wastes are valuable for soil-based agriculture. Faecal and bedding waste used as arable crop inputs increase nutrient retention capacity (cation exchange capacity) and physical condition of soils through improved water-holding capacity and soil structure.**
- **Solid waste, especially those with high C:N ratio, increase the demand for dissolved oxygen through high COD.**
- **Wastes with a high moisture content are expensive to transport.**
- **Rapid transfer of liquid wastes to pond systems reduces nutrient losses.**

Marketability of fish produced in livestock–fish systems

The trend for rising fish consumption in industrial economies, especially in countries with traditionally low consumption, is gaining momentum. Increasing affluence and the demonstrated health benefits of eating fish regularly appear to be important underlying reasons for this trend. The health benefits of polyunsaturated fatty acids contained in temperate, usually marine fish have also now been shown to occur in warm water carps (Steffens and Wirth, 1997)

The ecological benefits of eating such fish feeding low in the food chain rather than carnivorous species have yet to become a major marketing angle, but will undoubtedly become an issue. Currently, those marketing farmed fish make association with natural fish stocks and pristine environments. A key relative advantage of fish is that it is one of the few foods still available from natural environments; those marketing fish focus on the 'clean' and 'natural' credentials of their product. Sites are identified for their unpolluted nature, even though intensive aquaculture typically results in significant declines in downstream water quality. There are dangers, therefore, in any association of farmed fish with 'waste' of any type, especially in the light of increased consumer sensitivity to food scares in developed countries. Practically, a period of intensive fattening of waste-fed fish in a separate system should satisfy the need for ensuring consistent quality and for distancing the waste and the product eaten by the consumer. Another approach is to process fresh wastes through intermediate live feed organisms before feeding to fish consumed by people (Edwards, 1990). Using unprocessed livestock waste to produce fish up until the time of marketing may be unacceptable for consumers unaware of the realities of food production generally. Ironically, the rapid rise in demand for 'organic' products in industrialized countries may signal a change in attitudes from which fish farmed in organically fertilized, aquatic pastures may benefit.

Clearly, if waste-fed fish are to be acceptable to sophisticated urban consumers, a range of efforts will be required. HACCP principles need to be applied to reduce risks of pathogen transfer at all stages of production and processing. Different approaches to lengthening the food chain, rigorous monitoring of quality and a focus on the 'organic' qualities of fish produced will all support marketing of fish produced in this way.

9.6 Rural integration

A variety of factors affect opportunities for more integration of livestock and aquaculture in rural areas of developing countries. These relate to demography, as predominately rural societies

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BOX 9.D

Changing opportunities for smallholders to integrate egg-duck and fish production

Improved infrastructure, particularly road networks and availability of feed concentrates, has improved markedly over the last two decades in rural Northeast Thailand. This has raised opportunities for small-holders to intensify both livestock and fish production. Previous attempts to promote duck egg production integrated with backyard fish production had failed for a variety of reasons (Box 7.Q). A recent Department of Fisheries initiative to promote egg-duck integration with community fish production appeared to have potential as duck egg production was now viable even in remote areas. However, in practice small-scale production integrated with individually owned, or community fishponds, remained constrained by a variety of factors. Labour constraints forced holding the ducks around the homestead rather than over the water body and encouraged flocks to become larger. Wealthier people, usually women who could afford the regular cash investment, tended to specialize in duck egg production. Government programs purchasing duck eggs for children's school meals stimulated regular demand in the village but competition with cheaper chicken eggs distributed through networks of middlemen reduced profit margins. Many of these eggs were derived from layer operations, usually located in irrigated areas of the region, which were integrated with pond fish culture (Engle and Skladany, 1992).

urbanize and change their expectations and the nature of demand for food. Policies that promote livestock and aquaculture, especially with regard to the importation, production and marketing of feeds and breeds, are critical. Intensification of small-holders' livestock through developing alternative feeding strategies based on locally-produced and purchased feeds, is also considered

The availability of nutrients in rural areas is a major constraint to productivities of both terrestrial and aquatic systems. The role of extensive production methods for nutrient-poor situations is considered. A further issue of importance is the role of on-farm irrigation in agricultural development and how ponds deliver most benefits as a multipurpose resource.

Changing Demography and demand

Rural migration, while reducing labour for raising livestock and fish, also reduces demand for small-scale, locally produced livestock and fish. This can be compounded if improved roads and other infrastructure favours import of low-cost competing products into rural areas, further undermining demand for locally produced food. There is a tendency for large producers to squeeze small farmers in this way despite local poultry being considered superior to intensively farmed birds in most of Asia. Improved infrastructure can, however, allow import of productivity-enhancing inputs and access to urban markets (Box 9.D). This is particularly important as the agricultural work force ages and labour efficiency becomes critical for innovations to be sustained. Government policy to encourage rural livelihood options that include diversified agricultural, service and industrial development is required

Intensification using modern breeds and feeds

Modern breeds require balanced, high-value nutrition that can be produced with strategic imports even in resource-poor areas. If concentrates appropriate for blending with local grains and by-products are available, small holders can produce pigs and poultry very efficiently and benefit from the valuable nutrients for fish culture. One analysis in Northeast Thailand indicated that use of concentrates to complement local rice bran and cassava as a pig feed could increase herd size by a factor of 8 and the amount of fish by ten (Little and Satapornvanit, 1996). Government policy to actively encourage agribusiness to focus on the needs of small-holders by improving the

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availability to them of modern strains, feeds and veterinary services to them in rural areas is required. Decentralized livestock production and marketing will also benefit local consumers and service providers

Alternative approaches to intensification-novel feed and traditional breeds

In some situations local breeds and feeds have been found superior to those introduced Often a hybrid approach, in which local and introduced strains are hybridized and local feeds supplemented with improved varieties and inputs, is required on a practical level.

Understanding the nature of constraining factors is also important. A lack of dietary energy, rather than protein, has been found to limit the productivity of scavenging poultry and can best be improved through use of locally available supplements (Men, 1996). In contrast, protein is a major constraint to increasing productivity of penned local and hybrid pigs in Viet Nam. Low input strategies for monogastrics make use of both a natural ability to scavenge and omnivorous tendencies. Pigs utilize micro-organisms in the caecum and colon to digest materials unhydrolysed in the stomach and small intestine (Livingstone and Fowler, 1984). Diets of breeding animals can include a high proportion

BOX 9.E

Assessing efficiency of traditional, upgraded and modern livestock systems

Levels of input as well as output determine the efficency of production, by definition. Whereas the energy requirement of an intensively-reared White Leghorn is 300-320 kcal ME. bird^{-1} day^{-1}, a smaller native scavenging bird requires a minimum of 286 kcal ME. bird^{-1} day^{-1}, although lower levels of egg production are supported.

But, if under an intensive system 240 eggs. bird^{-1} can be produced but the total cost of inputs equals 220 eggs, the net production is only 20 eggs. bird^{-1}. In a scavenging system around 40 eggs. bird^{-1} can be produced without any additional feed costs, representing a net production of 40 eggs. bird^{-1}. Supplements used strategically may improve on this level of efficiency.

- **Strategic supplementation needs to understand seasonality and local differences in food available through scavenging (especially energy, crude protein, calcium and phosphorous). Significant differences were found in poultry from villages at different altitudes in the Central Highlands of Ethiopia.**
- **In Ethiopia it was concluded that energy-rich supplements should be given year-round, and protein supplements in the dry season, when availability of worms and young plant material was low.**

Concentrates that increased protein up to 100g protein. pig^{-1} day^{-1} increased live weight gain, cost effectively, by 83 percent (Nguyen, 1996). Even small amounts of commercially produced concentrates are often unavailable or prohibitively expensive in rural locations, however. Small fish regularly harvested as a by-product from a pond receiving livestock and other wastes could be used as a strategic feed supplement to enhance the productivity of livestock (Box 9.F). Alternatively, seasonal surpluses of wild and culture fish can be sun-dried or fermented for use throughout the year. The nutritional value of such approaches has been confirmed by trials in which waste-fed tilapia were tested as carnivorous fish and livestock feeds. The practice of using the fish pond as a feed source for penned livestock is already common in Northern Viet Nam where aquatic weeds are harvested and fed to pigs. The main issue is the likelihood that even small fish have a higher value for direct human food than the extra benefits to pig production from using them as a supplement. A simple analysis suggests that this strategy is unlikely to be attractive except where fish have low value.

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of bulky feeds if complemented by small amounts of cereal/concentrates. Conversion efficiencies of traditional strains of animals on low-input systems are poorer than modern breeds fed formulated rations, but environmental impacts and support costs are lower. When feeds are not given, or given in small quantities, such measures are not meaningful and 'efficiency' needs to be reassessed (Box 9.E). Very significant improvements in productivity can be attained using strategic feeding of locally available supplementary feeds to traditional varieties of scavenging poultry (Box 9 F)

Extensification - use periphyton

Chronic under-fertilization of ponds is a major problem in resource-poor farms throughout LDCs Lack of knowledge of the possible benefits, or a wish to avoid eutrophication of stored water for a variety of purposes, may explain this 'mismanagement'. More often a lack of available nutrients means that production is sub-optimal. Where land holdings and ponds are small and agriculture is intensive, efforts should be made to optimize plankton-based fish production often using inorganic fertilizer. In situations where ponds are larger and nutrient requirements to optimize autotrophic-based production are high, more strategic use of nutrients may be advisable. Research in Bangladesh has found that substrates placed in relatively infertile ponds to increase periphyton can almost double production of fish (Wahab *et al.*, 1999) A long established tradition in West Africa of using substrate to attract wild fish evolved into *acajada* systems in which periphyton growing on the substrate also becomes a food source for stocked fish.

A constraint to the wider adoption of these systems is the opportunity cost of suitable biomass. Wood and woody waste are in demand for fuel and other purposes in most LDCs. Intensification of ruminant livestock that involves growing leguminous multipurpose trees for

BOX 9.F

Feeding pigs on small fish

Assume: one pig raised from weaner to finisher over 150 days requires an extra 100 g protein. pig^{-1} day^{-1} to improve productivity and returns[1].
Assume: fresh, small-sized tilapia contain 62 percent crude protein on a DM basis, fresh tilapia are 76.8 percent moisture. Then, 696 g fresh fish. day^{-1} are required, or 105 kg over 150 days. The size of pond required to produce this amount would depend on the yield

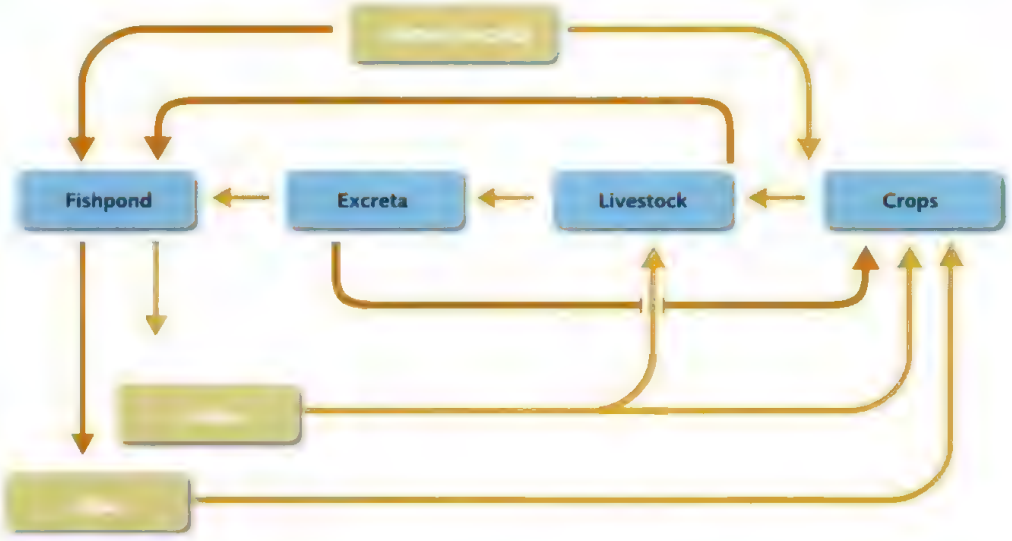
Fresh fish produced (kg) to support a 150 day pig production cycle in ponds of different sizes and yields.

Fish Yield (t ha^{-1} y^{-1})	Pond Area (ha)						
	0.01	0.02	0.05	0.1	0.15	0.2	0.3
0.5	2	4	10	20	30	40	60
1.0	4	8	20	40	60	80	120
1.5	6	12	30	60	90	120	180
2.0	8	16	40	80	120	160	240
2.5	10	20	50	100	150	200	300
3.0	12	24	60	120	180	240	360
3.5	14	28	80	140	220	280	420
4.0	16	32	100	160	260	320	480

Source [1]Nguyen (1996)

Figure 25

Schema of the major interactions between the various subsystems in a crop/livestock–fish integrated farming system



Source Edwards (1993)

fodder and fuel as borders, or on marginal land, is one strategy to increase both the availability of woody substrate and quality livestock feed

A further linkage between periphyton-based systems and livestock would be to soak substrate in livestock urine to increase periphyton growth and, subsequently, fish production

Water resources

The universal value of perennial water on-farm to enhance productivity and reduce drought- and flood-related loss has been greatly underestimated by institutions promoting fish culture. Water bodies, both community and household, have traditionally served a variety of functions in rural areas including livestock and fish production (Table 9.2). Maintaining or enhancing the multiple uses of water bodies may be the cornerstone of wider adoption of fish production by poorer people. Water bodies, whether ponds, weirs or small dams within watersheds, have important roles in nutrient conservation and concentration in addition to their primary function of water storage for downstream irrigation.

Irrigation of high-value vegetable and fruit crops planted around perennial ponds, and as successive plantings in the exposed sediments of seasonal ponds, have been shown to have greater impacts on household food security and income than the fish produced. In a range of models of pond-based fish and vegetable production in Ghana, fish yielded only between 1-2 percent of on-farm income (Prein and Ofori, 1996). Unsurprisingly farmers, especially women responsible for both production and marketing of such 'homestead' crops, often concentrate resources for vegetable production rather than optimising outputs of fish.

The relative size of the pond given the overall land holding, suitable conditions for pond construction, and availability of inputs (and fish yields), interact to determine the optimum for any given conditions In Northeast Thailand

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TABLE 9.2

Aspects of multipurpose use of a water body involving livestock and fish production

Feature	Constraints	Management
Source of drinking water for fish and livestock	• Should be low in bacteria, available year-round and easily accessible	• Control nutrient inputs • Excavate a shallow well to filter water
Large livestock wallowing in pond	• Increased turbidity reduces productivity of pond	• Restrict access to shallow end • Facilitate access though design to reduce physical damage to pond
Water birds swimming	• Can cause erosion of pond embankments	• Design and location of feeding station and pen
Source of feed for fish and livestock e.g. small fish, snails and shrimp	• Competition for direct human food	• Consider design to ensure micro-habitats within water bodies
Source of water weeds for fish and livestock	• Competition for human food	• Design and management to ensure biodiversity maintained

construction of ponds to alleviate water shortages in rainfed areas has been widely promoted through subsidised construction and extension. Linear programming has been used to investigate optimal resource use and it was found that earthen ponds of 1 000 m^2 can produce over 20 percent of farm income on mixed farms in which vegetables, rice and cassava are the other main crops (Setboonsarng and Edwards, 1998)

Potential

Trends in food production and consumption within Asia point to large inequalities between and within countries High-income countries in East and Southeast Asia are consuming more meat and fish in absolute terms and as a proportion of the total diet than before. In contrast, rural livelihoods in poorer countries, particularly among marginalized people, may be deteriorating in terms of diet and overall welfare. Whereas small-scale farms in South and Southeast Asia raising livestock and fish are typically crop-dominated and nutrient-poor, industrial commercial livestock farms are nutrient-rich and may have significant environmental impacts if wastes are not recycled Traditional livestock systems may not produce wastes in either enough quantity or of suitable quality to sustain current grain crops The use of these wastes for aquaculture may therefore have negative impacts elsewhere in the farming systems. In contrast, modern systems tend to be concentrated in peri-urban areas where use of wastes to fertilize either field crops or fishponds is impractical.

Under certain conditions a fishpond could become the focus for diversification of small-scale farms in developing countries Ponds in which fish are stocked can be used for the strategic irrigation of both crops and livestock. Integrated water use for agricultural and domestic purposes is often the primary incentive for incorporation of fish culture on-farm. The purposeful production of crops for feeding to fish directly, or to livestock, and livestock manure being used as pond inputs has shown potential (Figure 25).

However, several factors may hamper synergism between crops livestock and fish. In areas with the greatest need for integrated

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What factors stimulate feed or waste-based aquaculture?

Source: modified from FAO (1997a)

farming, rural overpopulation may have led to land holding fragmentation, constraining the physical integration of livestock and crop production near the pond. Industrialization and migration can make the opportunity costs of growing on-farm feeds, raising livestock and/or using wastes less attractive. Fish may also compete with livestock for certain feeds, particularly valuable crop by-products. Some degree of intensification of livestock may be necessary to make their production viable and their wastes more valuable and available for fish culture. Inorganic fertilizers can be profitably used to 'spare' limited amounts of animal manure, especially when live or fresh fish can be marketed locally at high prices. A judicious mix of traditional and introduced inputs may often be the most practical approach.

Rapid economic development in the Asia Pacific over the last two decades has been a major stimulus to the dynamic growth of livestock and fish production in the region. The rise of agro-industry and its role in the introduction of modern strains and feeds have been particularly important. Demand and use of formulated, balanced diets has grown rapidly, particularly for pigs and poultry, and to a more limited extent for cattle. Pingali (1995) explains this is a natural result of increasing demand, rising labour and declining transport costs. Where feed industries are established, predicting the development of feed-based or waste-based aquaculture also becomes a major issue (Figure 26).

The major challenges are to assess the role of livestock–fish integration to improve both the livelihoods of small-scale, rural households and to make cultured freshwater fish affordable for poor urban consumers.

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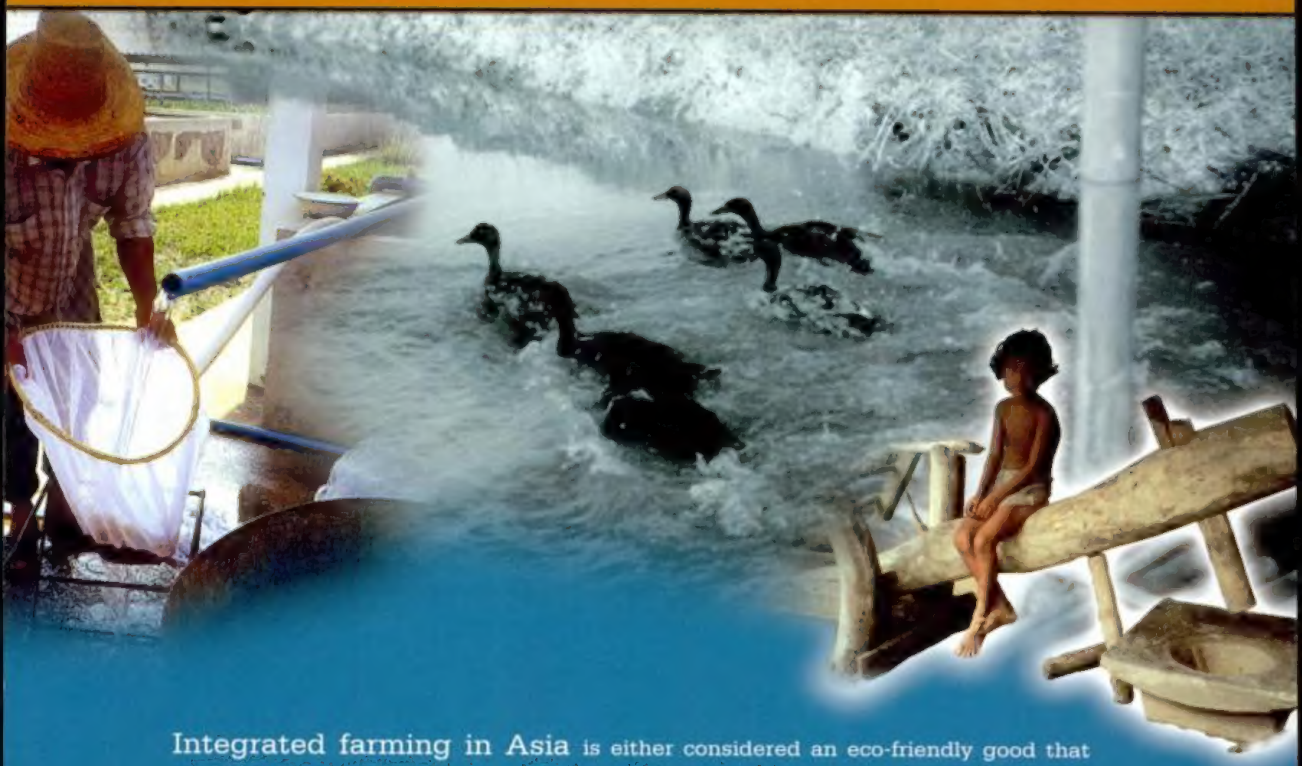

Integrated farming in Asia is either considered an eco-friendly good that should be preserved for environmental reasons or a poor practice that will soon be superseded by industrial aquaculture. The reality, as this book describes, is a dynamic set of practices that have expanded rapidly under certain conditions but have proved inconsequential in others. An analysis concludes that most livestock-fish integration is sound business conducted by entrepreneurs accessing urban markets where the price of fish is relatively low. It can be used as part of a strategy to reduce environmental impacts of intensive livestock production and to produce low-cost food. Farmers have proved adept at both developing their systems to meet their own needs and diversifying the role of ponds, fish and livestock within their complex livelihoods. This overview identifies the factors that lead to success or failure and gives an insight into both concept and practice.

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